Development of Roof Insulation Material from Low Density Polyethylene (LDPE), Kapok Fibre and Maerogel

by

LIAN JIA-JIE

16546

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil)

JANUARY 2015

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Development of Roof Insulation Materials from Low Density Polyethylene (LDPE), Kapok Fibre and Maerogel

by

LIAN JIA-JIE
16546

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(Civil)

Approved by,

____
(Prof. Ir. Dr. Muhd Fadhil Nuruddin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

(LIAN JIA-JIE)

ABSTRACT

The roof thermal performance exerts a strong influence in controlling the building's interior temperature. In Malaysia, people are suffering of the hot weather throughout the year especially during daytime. This research aims to develop the most effective roof insulation materials. In order to achieve that, three types of composite roof insulation samples are created through compression molding. Besides, tensile test and thermal conductivity test are conducted. Also, simulation of the thermal performance of the composites are done by using Autodesk Ecotect. All of the composites are found to be effective as they capable to maintain the indoor temperature at lesser than $34°C$ which is the limit of acceptable thermal comfort temperature limit *(Makaremi, Salleh, Jaafar, & GhaffarianHoseini, 2012; Wijewardane & Jayasinghe, 2008)*. Also, it is found that kapok fibre and maerogel incorporate with the matrix, LDPE has the lowest thermal conductivity which is 0.485 W/mK. Besides, in the analysis of hourly temperature difference graph calculated by Ecotect, it shown that kapok fibre composite has slightly better thermal performance in insulating heat from outdoor to indoor. It is deduced that the tensile and thermal properties of the composite are dominated by the matrix, which is 94% of LDPE which lead to small difference in tensile strength and thermal performance of the composites. In sum, kapok fibre + maerogel + LDPE is the most effective composite roof insulation samples and it is comparable to the common insulation materials. In conclusion, it is a big new step to develop kapok fibre and maerogel which are brittle and fragile but having low density and thermal conductivity as a new kind of thermal insulation materials.

ACKNOWLEDGEMENT

First and foremost, I would like to express my deepest gratitude to Universiti Teknologi Petronas (UTP) to offer and include Final Year Project as a part of the requirement for Bachelor of Engineering (Hons) in Civil Engineering as a platform for final year students to learn and gain experience as a researcher.

Next, I would like to extend my appreciation to both my research supervisor, Prof. Ir. Dr. Muhd Fadhil Nuruddin and my mentor, Nadzhratul Husna Ahmad Puad who guide me and help me a lot throughout the final year project. Their advices, supervision and guidance are very valuable and helpful in completing my final year project.

Last but not least, I would like to thanks the lab technician, Paris B Mohd Said who assist me in using the lab facilities such as compression molding machine and conduct the tensile test for my composite insulation samples.

Lastly, my thanks and appreciations go to my family, they always give total support in various aspects along the completion of the final year project. With their encouragement and inspiration, I am able to complete my final year project effectively and efficiently.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

Tropical climatic conditions prevail in many countries that located near to the equator. In Malaysia, the climate is categorized as equatorial whereby the weather is hot and humid throughout the year articulated with low daily temperature variations. Besides, it is normal that the ambient air temperature in developing countries is corresponding high especially in the large cities. As one of the developing countries, Malaysia is experiencing rapid development which led to higher energy demand for thermal comfort. Among the various building services, heating, ventilation and air-conditioning (HVAC) systems account for almost 50% of building's total energy consumption in the developed countries (Pérez-Lombard, Ortiz, & Pout, 2008). While in America, space heating and cooling responsible for 50% to 70% of its energy use (Al-Homoud, 2005). Besides, (Pérez-Lombard et al., 2008) also posited an upward trend of air-conditioning use in the future because of the increasing demands of indoor comfort among the occupants.

In addition, the roof surfaces of a building are often exposed to solar radiation between sunrise and sunset. Therefore, roof and attic of a building are account for a considerable part of the thermal load. Consequently, occupants rely very much on fans and air-conditioning in order to acquire thermal comfort and subsequently increase the electrical energy consumption required for cooling. However, the extensive use of air-conditioning will not only cause immense burden on the electrical energy demand but also causes many environmental issues such as urban heat island effect and global warming. In sum, the main cause of the high air-conditioning load is due to large amount of solar heat gain of the building envelope. Therefore, the thermal performance of the roof is widely studied in recent years. Indeed, improve the thermal performance of the roof insulation material is the most effective way to curb the air-conditioning load and to improve the indoor thermal comfort for the occupants.

Hence, this research aims to develop the most effective composite roof insulation materials from two new materials which are kapok fibre and maerogel together with the matrix, low density polyethylene (LDPE). Generally, three types of composite roof insulation samples will be created at which their thermal properties and tensile properties will be tested. Also, their respective thermal properties will be used to simulate the thermal performance of the thermal insulated experimental houses in Autodesk Ecotect. The main output of the simulation is the hourly temperature graph which shows the outdoor and indoor temperature of three modelled houses installed with three different composite roof insulation materials. Eventually, the outdoor-indoor temperature difference graphs will be plotted to determine the most effective roof insulation materials which has the highest performance in insulate heat from outdoor to indoor of the modelled house in simulation.

1.2 PROBLEM STATEMENT

Malaysia is a country that located near to the equator. The weather in Malaysia is mostly hot and humid the whole year articulated with low daily temperature variation. Ong (2011) claims that the ambient air temperature and relative humidity of Malaysia as a tropical country fall in between 26°*C*-40°*C* and 60%-90% respectively. In such condition, it is unfavorable, uncomfortable to the occupants and reduces the productivity of the daily activities of occupants accordingly. Hence, buildings' capability to insulate heat is the main factor in reducing heat to ensure good indoor thermal comfort. Building insulation is generally referring to wall insulation and roof insulation. However, roof insulation is more critical whereby 60% of thermal transfer occur at the roof (Soubdhan, Feuillard, & Bade, 2005). While Vijaykumar, Srinivasan, and Dhandapani (2007) explained that roof is accountable for 70% of heat gain in most of the low rise buildings in Malaysia.

Generally, roof is the most vulnerable part of the building envelope which cover to uppermost part of the building to provide protection from animals and weather, especially heat, sunlight, rain and any other kind of natural hazards. During the hot days, the roofs of the buildings are heavily exposed to the hot sun directly. Also, the heat from the sunlight will passes through the roofs and heat up the room temperature. As a result, high room temperature will causes thermal discomfort to the occupants. As far as is concerned, occupants emphasize thermal comfortability very much. Consequently, occupants tend to consume large amount of energy mainly for the ventilation and air conditioning to improve indoor thermal comfort. However, wide use of air conditioning units and fans will caused a shift in electrical energy consumption and increase electricity demand. According to Pérez-Lombard et al. (2008), HVAC (heating, ventilation and air-conditioning) systems account for approximately 50% of buildings' total energy usage among the building services in the developed countries. Eventually, extensive use of air conditioning and fans will brings negative effects to the environment such as global warming. Therefore, it is important to develop roof insulation materials which can increase the thermal performance of the roof itself.

Regardless, until now, there is still does not have any reported research done about adopting kapok fibre and maerogel in the development of roof insulation materials. Also, adopting kapok fibre and maerogel in roof insulation materials might be difficult because these materials are very brittle and fragile. In sum, the research gap make this research become more challenging.

1.3 OBJECTIVE

1. To determine the tensile property and effectiveness of the three types of composite roof insulation materials which compose of :

a) Aluminum Foil + Low Density Polyethylene + Maerogel

b) Stone Wool + Low Density Polyethylene + Maerogel

c) Kapok Fibre + Low Density Polyethylene + Maerogel

2. To evaluate the thermal performance of these composite roof insulation materials by using Autodesk Ecotect.

1.4 SCOPE OF STUDY

1. Determination of the thermal conductivity of the three types of composite roof insulation samples.

2. Evaluation of the tensile properties of the three types of composite roof insulation samples by carrying out tensile test.

3. Simulation of the thermal performance of the thermal insulated experimental houses which are installed with three different composite roof insulation materials at their roof attic by using Autodesk Ecotect.

4. Analysis of the hourly temperature profiles of thermal insulated experimental house that are generated by Autodesk Ecotect.

CHAPTER 2
LITERATURE REVIEW

2.0 LITERATURE REVIEW

2.1. THERMAL COMFORT IN TROPICAL CLIMATE

In Malaysia, the climate is categorized as equatorial; the weather is hot and humid throughout the year. Buildings' insulation is always an important factor to achieve thermal comfort for its occupants. Ong (2011) claims that the ambient air temperature and relative humidity of Malaysia as a tropical country fall in between 26°*C*-40°*C* and 60%-90% respectively. In addition, this type of climate is not favorable for occupants and reduces the productivity since it brings uncomfortable conditions to occupants.

Indeed, a good thermal comfort condition is very important to provide a comfortable and productive living environment to the occupants. Generally, thermal comfort is influenced by the environmental condition and the psychological condition of occupants. For instances, the factors that influence the environmental conditions are surrounding temperature and humidity whereas the psychological condition of an occupant is influenced by the activities and clothing. Hussein, Rahman, and Maria (2009) had done a field studies regarding the thermal comfort conditions that were held out in air-conditioned and non-air conditioned buildings in Malaysia. They found out that the acceptable range of temperature in an air-conditioned buildings were 23.1°*C* to 25.6°*C* while preferable temperature range in non-air conditioned buildings were 26.0°*C* to 30.7°*C.*

In the other hand, Makaremi et al. (2012) had done a research on thermal comfort acceptable condition that focus the shaded outdoor spaces inside University Putra Malaysia. In their studies, PET (physiologically equivalent temperature) index is used to determine and measure the thermal comfort conditions in selected areas. Makaremi et al. (2012) concluded that the thermal comfort conditions in the selected areas which is measured in temperature were higher than the comfort range defined for tropical climate (PET < 30°*C).* Whereas the acceptable conditions (PET < 34°*C)* is commonly happened in the morning, roughly between 9am-10am and in the late afternoon, between 4pm to 5pm.

Besides, a field measurements was conducted by Wijewardane and Jayasinghe (2008) to assess the thermal comfort temperature range for the workers who work in the factories in hot and humid tropical climate. Wijewardane and Jayasinghe (2008) concluded that the workers that involve in light factory work can sustain their productivity and acclimatize in a working environment of temperature up to $30°C$ without much ventilation. Also, the temperature limit to sustain the thermal comfort level can be raised up to $34°C$ as long as the indoor air velocities are maintained not lower than or as high as $0.6ms^{-1}$.

2.2. ROOF INSULATION

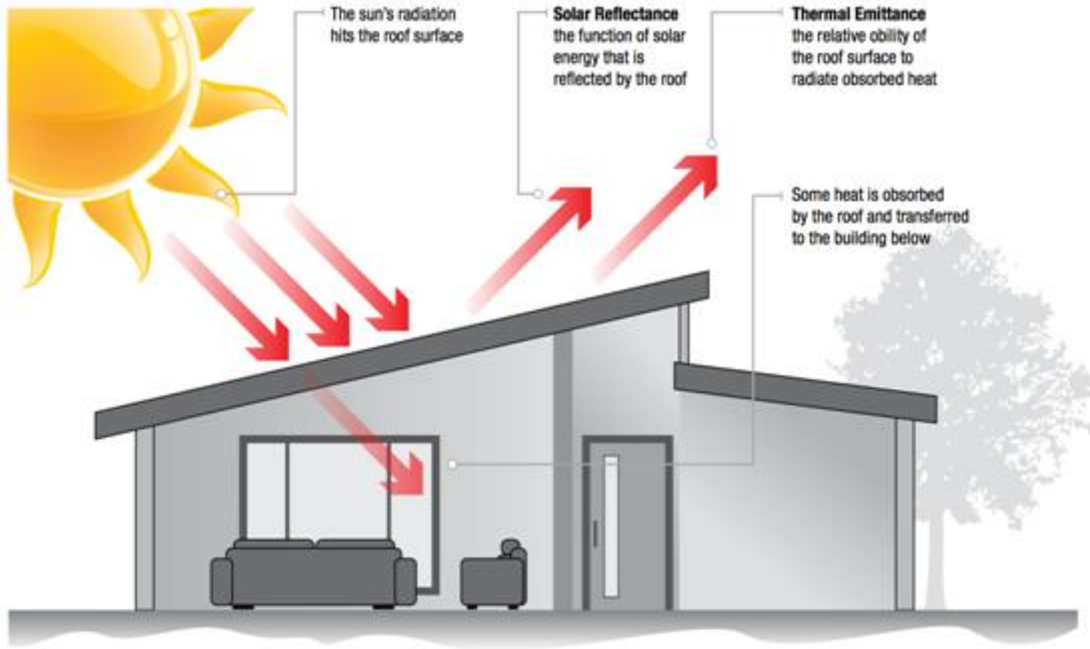


Figure 2-1 *Building that exposed to direct sunlight, taken from ("Roof Insulation | Cool Roof Malaysia,")*

Generally, the roof surfaces of a building are exposed to the solar radiation throughout the daytime. Jayasinghe, Attalage, and Jayawardena (2003) state that roofs are contribute enormously to building heat gain as compared to walls mainly because the roofs are exposed to the hot sun between sunrise and sunset. It is believed that sixty percent of the thermal transfer happens through the roof (Soubdhan et al., 2005). Also, among the residential buildings, most of the low rise buildings in Malaysia are found to experiencing high intensity of heat transmission from the building envelope whereby the roof account for 70% of heat gain (Vijaykumar et al., 2007).

Ong (2011) and Yew et al. (2013) explained that heat from solar radiation will be absorbed by the roofs and it is transmitted through and trapped in the attic which is then lead to hot ceiling. Then, the hot ceiling will radiate the heat to the occupants inside a building. In the case that a building without a ceiling, heat will directly exposed to the occupants under the roof. Therefore, the thermal insulation of roof is very important as roof insulation dictate the thermal insulation of a building.

In addition, Soubdhan et al. (2005) had conducted an experiment to evaluate the performance of insulation in roofing system under tropical climate. One of the findings of his research is regardless of the absorptivity of the roof, the radiative heat flux can be reduced from 33% to 37% by adding radiant barrier in roofing system.

Last but not least, Tong et al. (2014) also conducted an experiment to evaluate the thermal performance of concrete-based roofs in tropical climate by using modified Complex Fast Fourier Transform (CFFT) method. They found out that the cooling effect of the less insulated unventilated roofs is more significant than that in ventilated roofs during the daytime. Also, every increase of 10% of solar reflectivity will reduce the heat gain of the roof by 11%. In sum, the high roof thermal resistance will help to lower down the temperature of the ceilings during daytime. However, this situation is reversed at night. Regardless, adopting concrete-based roof in tropical climate can aid in heat reductions of 42% to 84% depending on the roof configuration.

2.3. THERMAL INSULATION

Thermal insulation is referring to a material or combination of materials that will reduce or obstruct the heat flow by conduction, convection and radiation when it is properly applied. Basically, thermal insulation retards heat flow into a building due to its high thermal resistance. Thermal insulation materials have an important role and proven to be the logical first step to reduce the air-conditioning load to keep a good interior temperature and therefore achieve energy efficiency of a building (Al-Homoud, 2005; Mazor, Mutton, Russell, & Keoleian, 2011). Besides, the thermal conductivity of a material is the amount of energy conducted through a body of unit area, and unit thickness in unit time when the difference in temperature between the faces causing heat flow is unit temperature difference (Rajput, 2007). Usually, thermal conductivity which also known as k-value is expressed in W/mK (watt per metre Kelvin) and W/m°*C* (watt per metre Celsius).

The thermal conductivity of the roof insulation materials will be calculated by using the general thermal conductivity equation as shown below:

$$\boxed{k = \frac{\mathrm{QL}}{\mathrm{A\Delta T}}}$$

Where:

k = thermal conductivity (W/m.k)

Q = heat flow (Watts)

L = Length of heat transfer path (m)

A = Effective area of heat transfer (m^2)

ΔT = Temperature difference between heat source and heat sink

Taken from “Insulation Materials, Testing, and Applications” (McElroy & Kimpflen, 1990).

Besides, thermal resistance or R-value which is expressed in m^2-K/W is a measure of the resistance of heat flow which is resulted from suppressing conduction, radiation and convection. Thermal resistance is a function of material thermal conductivity, density and thickness. The higher the R-value of a material, the better it thermal insulating properties. The relationship between R-value and heat flow reduction is illustrated in Table 2-1.

Insulation R-value	**Amount of Heat Flow Reduction**	**Improvement in Energy Efficiency vs. R-8 Insulation**
R-8	90%	-
R-12	93%	3%
R-16	95%	5%
R-20	96%	6%
R-32	97%	7%

Table 2-1 *Relationship between R-value and Heat Flow Reduction.*

Taken from ("Energy Efficiency ").

Also, R-value is the reciprocal of U-value, which is the thermal transmittance(Al-Homoud, 2005). Thermal transmittance is the rate of heat flow through a unit surface area of a component with unit (1K) temperature difference between the surfaces of the two sides of the component. U-value is expressed in W/m^2-K and as below:

$$\boxed{U = \frac{1}{R} = \frac{Q_A}{\Delta \mathrm{T}} = \frac{k}{L}}$$

Where:

k = thermal conductivity (W/m.k)

Q = heat flow (W)

L = thickness of material

R = thermal resistance

2.4. INSULATION MATERIAL

Throughout the years, insulating materials with low thermal conductivity values, preferably less than 0.04 W/m-K have been developed in order to minimize the energy consumption of buildings in thermal protection(Papadopoulos & Giama, 2007). Basically, there are many forms of insulation materials including roll form, loose-fill form, rigid form, reflective form and etc. The selection of type and form of insulation materials are depending on the kind of application as well as the desired material's properties in thermal, physical, chemical and etc. The most widely used types of thermal insulation materials are organic foamy materials (expanded and extruded polystyrene and, to a small extend, polyurethane), inorganic fibrous (glass-wool and stone-wool) and other materials account for the remaining 10% of the market (mainly wood-wool). Also, there are some atypical materials, like transparent insulating materials and "ecological" materials based on agricultural raw materials can barely found and limited in the market due to their high cost.

Nevertheless, Wei et al. (2014) has developed a new thermal insulation material which is named as RSTIB from rice straws. RSTIB developed and manufactured by using high frequency hot pressing method. This newly developed insulation materials has low density of 200-350kg/m^3 and low thermal conductivity of 0.051-0.053W/m.K with a thickness of 40mm. Wei et al. (2014) also added that RSTIB could be used as an important construction material for wall and roof insulation which can aid in conservation of energy.

2.4.1. KAPOK FIBRE

Kapok fibers are the fruit fibers of kapok tree, which is abundant and inexpensive natural cellulose fiber that is originated in tropical India and Southeast Asia. It is also known as Ceiba pentandra (L.) Gaertn. Kapok fiber is a natural plant fiber which is a silky, yellowish and cotton-like substance that encloses the seeds in the pods of the kapok tree(Lim & Huang, 2007; Tye, Lee, Wan Abdullah, & Leh, 2012; Wang & Zhou, 2008). Kapok fruits are rich in natural cellulose fibers (Tye et al., 2012). Kapok fiber has a significant homogeneous hollow tube shape which as wall thickness of ca. 0.8µm to 1.0µm and diameter of 8.0µm to 10 µm. Besides, Chung et al. (2009) stated that kapok fibers are mainly made up of 48% cellulose, 28% xylan and 19%

lignin.Tye et al. (2012) also added that kapok fiber is similar to cotton, it consists of single cell fiber which is mainly cellulose on its lignocellulosic system Lim and Huang (2007).

Lim and Huang (2007) said that kapok fiber is lightweight, fluffy, non-allergic, non-toxic, resistant to rot and odorless; it also has lower density, higher porosity and greater specific surface area than other agricultural products. Conventionally, kapok fibers are used as stuffing material for beds and pillows (Lim & Huang, 2007; Tye et al., 2012). In recent years, kapok fibers are widely used as sorbent material in oil spill area, non-woven fabric for plastic green house and acoustic absorbing material(Chung et al., 2009; Lim & Huang, 2007). Lim and Huang (2007) also added that kapok is also used as stuffing for bedding, life preservers, upholstery and other water-safety equipment due to it has very good buoyancy. Other than that, kapok is used for insulation against heat and sound because it air-filled lumen.

In addition, experiments was done by Chung et al. (2009) to convert the kapok fiber to flame-resistant fiber by removing the combustible compound of kapok through the exposure to gamma radiation. Regardless, there is research gap in developing kapok fibre as a new insulation material.

Reference	**Flame Resistant**	**Heat Transfer**	**Heat Retention**	**Acoustic**	**Roof Insulation**
Chung et al. (2009)	✓				
Cui, Wang, Wei, and Zhao (2009)		✓			
Song and Yu (2011)		✓			
Dieng et al. (2012)			✓		
Xiang, Wang, and Liua (2013)				✓	

Table 2-2 *Research gap of kapok fibre.*

According to **Table 2-1**, researches have been done in determining the properties of kapok fibre with respect to flame resistant, heat transfer, heat retention and acoustic properties. However, until now, there is still does not have any reported research about adopting kapok fibre as one of the roof insulation materials.

In sum, there is still lack of research on kapok fiber to be used as roof insulation material. Nevertheless, it is believed that kapok fibers have the potential to be developed as an effective roof insulation material owing to its low thermal conductivity at about 0.03 to 0.04 W/m.K and low density at 0.29g/cm^3 (Cui et al., 2009).

2.4.2. MAEROGEL

Maerogel is one of the greatest and commendable nano products in Malaysia which is discovered and produced by Prof. Dr .Halimaton. Prof. Dr. Halimaton is an excellent researcher who discovered a cheap way to produce maerogel from rice husk. Maerogel is a high-tech material that converted from the discarded rice husks which can help to cut down electricity bills, protect buildings from bomb blasts and reduce the weight of airplanes and tennis rackets (Zulkifli, Yajid, Hamdan, & Muhid, 2014). (Zulkifli et al., 2014) mentioned that maerogel is actually silica aerogel that produced from rice husk. Actually, aerogel has been around since 1931. However, high production cost of aerogel has limited its use. It is arguably that maerogel can reduce the production cost of aerogel by 80% which giving a hope to the public that maerogel is affordable by public and can be commercialized with its wide uses.

In addition, maerogel is an inert, non-toxic and environmental friendly amorphous material which also possesses established physic-chemical properties that is alterable for many kinds of applications. In sum, maerogel is a more advance version of aerogel in term of quality if compare to the aerogels that existed in the markets.

Maerogel has low apparent density of 0.03g/cm^3 and low thermal conductivity of 0.03W/m.K (Rajalingam, 2013; Zulkifli et al., 2014). (Zulkifli et al., 2014) also explained that maerogel is a superior thermal insulator because it is nearly weightless. Also, maerogel provides seven-fold better insulation than fiberglass. Furthermore, maerogel can be utilized in vacuum and thermal insulation of boilers, water tanks and refrigerators. In conclusion, maerogel has the potential to become an effective roof insulation material as it is proved to be an excellent thermal insulator which is weightless and has low density.

2.4.3. LOW DENSITY POLYETHYLENE

Low density polyethylene or LDPE is a thermoplastic that is made from the monomer ethylene. Generally, LDPE is manufactured in the industries by using high pressure process through free radical polymerization. LDPE has low density which is about 0.92 g/cm^3 and thermal conductivity of 0.33W/m.K. The common application of LDPE are manufacturing of variety types of containers and molded laboratory equipment due to its good chemical resistance properties. While in construction, LDPE is normally manufactured as sealing membrane for water pond and waterproof membrane for protection barrier on green roofs.

A study was conducted to determine the effect of crystallinity and irradiation on thermal properties and specific heat capacity of LDPE by Borhani zarandi, Amrollahi Bioki, Mirbagheri, Tabbakh, and Mirjalili (2012). In their findings, they found out that at a prescribed temperature range, the thermal conductivity of LDPE is reducing by increasing the dose of irradiation. Also, as the weight fraction of crystallinity increase, the thermal conductivity of LDPE is increased whereas the specific heat capacity of it is reduced.

2.5. OPTIMUM THICKNESS OF INSULATION MATERIAL

The thickness of roof insulation material is one of the factors affecting the thermal performance of the roof. The use of adequate thickness of roof insulation material on the building envelope is one of the most efficient ways to reduce the air temperature inside a building. Generally, the insulation materials' thickness is chosen by considering the average ambient temperature of the area, thermal conductivity and the cost of the insulation materials (Sisman, Kahya, Aras, & Aras, 2007).

Generally, the roof insulation materials' optimum thickness is varies accordance to the location and climate. Bektas Ekici, Aytac Gulten, and Aksoy (2012) had conducted a study on the optimum insulation thickness of different types of external walls by using different insulation materials in Turkey. They found out that the optimum thickness of insulation materials varies in between 0.2cm and 18.6cm; saving the energies in between 0.038$/m^2 and 250.41$/m^2; the payback period is differ between 0.714 years and 9.104 years. These findings are depending at the location and type of insulation materials tested. In the other hand, Yu, Tian, Yang, Xu, and Wang (2011) also conducted a research to determine optimum insulation thickness of residential roof with respect to solar air degree-hours in cold winter zone and hot summer zone of China. They found out that the expanded polystyrene with deep colored surface has highest optimum thickness which is 0.187m and the most life-cycle savings of 112.25$/m^2 at Changsa, China.

Regardless, most of the researchers, Sisman et al. (2007), Bektas Ekici et al. (2012) and Yu et al. (2011) shared the same opinion that increasing the thickness of insulation material will reduce the energy consumption for cooling and heating but increase the initial cost. Also, it is understood that increasing extra thickness of insulation material beyond the optimum thickness will not increase energy savings. In sum, determination of optimum thickness of roof insulation material is imperative.

2.6. CRITICAL ANALYSIS

Previously, there are many researches have been done related to the roofing system and roofing insulation materials by using different method. The findings of the researches are illustrated in Table

No.	Author	Year	Title	Findings
1	Soubdhan, T. Feuillard, T. Bade, F.	2005	Experimental evaluation of insulation material in roofing system under tropical climate.	• Disregarding the roof absorptivity, adding radiant barrier in roofing system will significantly reduces the radiative heat flux from 33 % to 37%.
2	Tong, Shanshan Li, Hua Zingre, Kishor T Wan, Man Pun Chang, Victor W-C Wong, Swee Khian Toh, Winston Boo Thian Lee, Irene Yen Leng	2014	Thermal performance of concrete-based roofs in tropical climate	• Increasing solar reflectivity by 10% will reduces the daily heat gain of tropical concrete roofs by 11% • About 42-84% of daily heat gains can be reduced in tropical concrete roofs by passive technologies.
3	Wei, Kangcheng Lv, Chenglong Chen, Minzhi Zhou, Xiaoyan Dai, Zhenyu Shen, Da	2014	Development and performance evaluation of a new thermal insulation material from rice straw using high frequency hot-pressing	• A new thermal insulation material (RSTIB) from rice straws with a low density of 200–350 kg/m^3, a thickness of 40 mm and the thermal conductivity of 0.051–0.053 W/(m K) was developed using high frequency hot-pressing.
4	Borhani zarandi, M. Amrollahi Bioki, H. Mirbagheri, Z. A. Tabbakh, F. Mirjalili, G.	2012	Effect of crystallinity and irradiation on thermal properties and specific heat capacity of LDPE & LDPE/EVA	• Thermal conductivity of LDPE at a prescribed temperature range decreased by increasing the irradiation dose. By increasing the weight fraction percentage of crystallinity, the thermal conductivity of LDPE increased, whereas C_p (specific heat capacity) of this material is decreased.

5	Bektas Ekici, Betul Aytac Gulten, Ayca Aksoy, U. Teoman	2012	A study on the optimum insulation thicknesses of various types of external walls with respect to different materials, fuels and climate zones in Turkey	• The optimum insulation thickness varies between 0.2cm and 18.6 cm, energy savings vary between 0.038$/m^2 and 250.415$/m^2 , and payback periods vary between 0.714 and 9.104 years depending the location and type of insulation materials.
6	Yu, Jinghua Tian, Liwei Yang, Changzhi Xu, Xinhua Wang, Jinbo	2011	Optimum insulation thickness of residential roof with respect to solar-air degree-hours in hot summer and cold winter zone of china	• Expanded polystyrene with deep colored surface has highest optimum thickness of 0.187m and highest life cycle savings of 112.2$/m^2 at Changsa, China.

Table 2-3 *Previous Researches and Respective Findings*

Nonetheless, there is research gap in developing kapok fibre as a new insulation material. As shown in **Table 2-3**, researches have done several research regarding the flame resistant, heat transfer, heat retention and acoustic properties of kapok fibre. However, there is no any published research about using kapok fibre as one of the main component in construction material for roof insulation and wall insulation.

Reference	Flame Resistant	Heat Transfer	Heat Retention	Acoustic	Roof Insulation
Chung et al. (2009)	✓				
Cui et al. (2009)		✓			
Song and Yu (2011)		✓			
Dieng et al. (2012)			✓		
Xiang et al. (2013)				✓	

Table 2-4 *Research gap of kapok fibre.*

CHAPTER 3

METHODOLOGY

3.0 METHODOLOGY

3.1. EXPERIMENT FLOW CHART

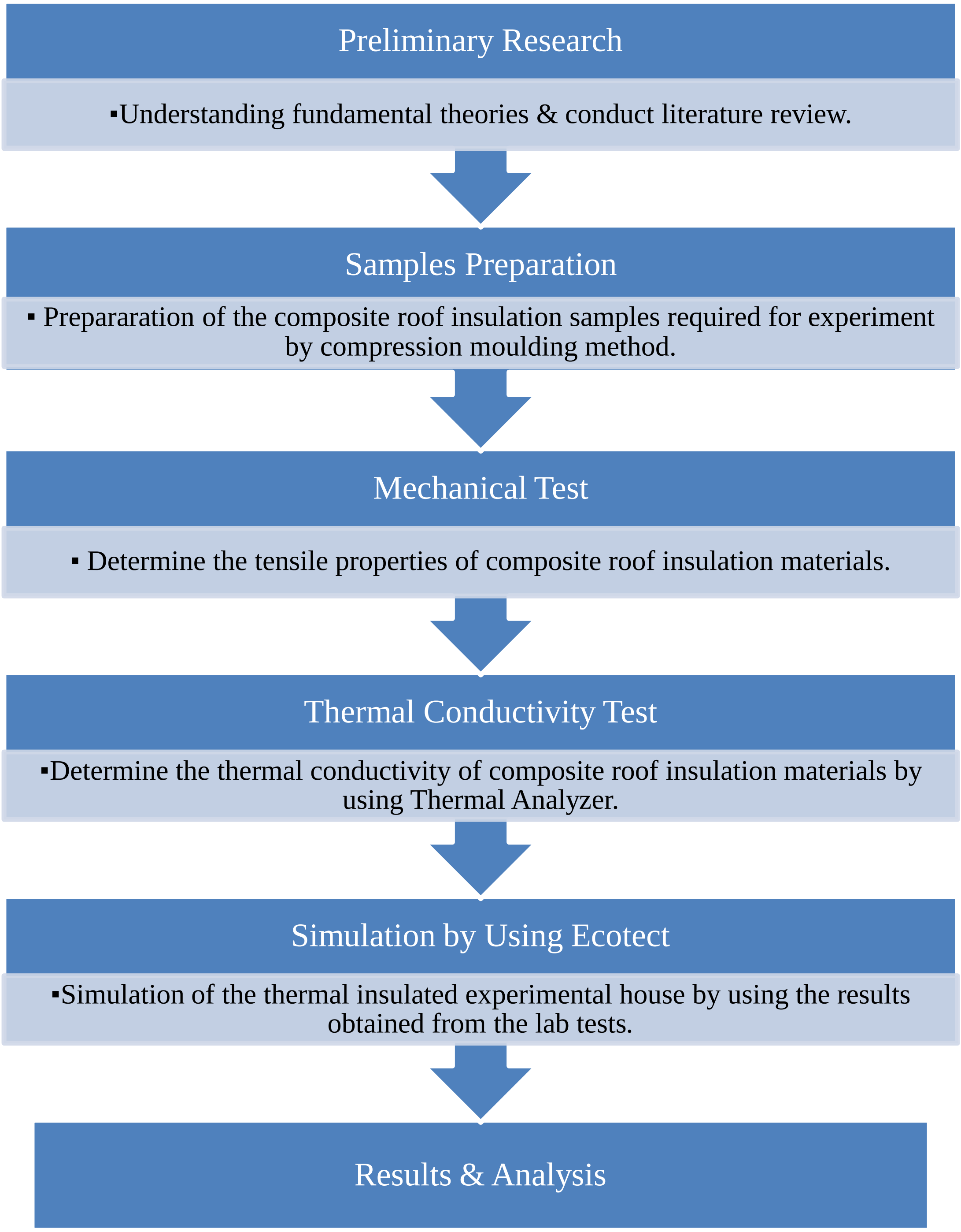
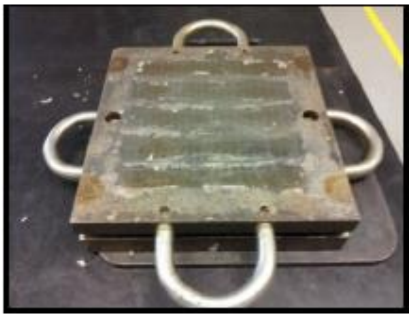


Figure 3-1 *Experiment Flow Chart*

3.2. TOOL & EQUIPMENT

EQUIPMENT	FUNCTION
Monarch Hot Compression Machine 	Use to preheat and compress to composite roof insulation materials.
Universal Testing Machine (LLYOLD LR Series) 	Utilize to carry out tensile test.
Compression Mould 	Use to mold, compress and shape the composite roof insulation materials.

EQUIPMENT	FUNCTION
Mettler Toledo Electronic Balance 	Use to weigh the LDPE pellets, stone wool, aluminium foil, kapok fibre and maerogel.
C-THERM Thermal Analyzer 	Use to measure the thermal conductivity of composite roof insulation materials.
Autodesk Ecotect 	Use for simulation of the experimental house with difference composite roof insulation materials.

3.3. SAMPLES PREPARATION

The samples of composite roof insulation materials will be prepared according to the weight ratio as stated in **Table 3-1** below.

Sample	Materials	Matrix (LDPE) (wt. %)	Aluminum Foil (wt. %)	Stone Wool (wt. %)	Kapok Fibre (wt. %)	Maerogel (wt. %)	No of Samples
A	**Aluminum Foil + LDPE + Maerogel**	94	4	-	-	2	5
B	**Stone Wool + LDPE + Maerogel**	94	-	4	-	2	5
C	**Kapok Fibre + LDPE + Maerogel**	94	-	-	4	2	5

Table 3-1 *Composition of composite roof insulation samples.*

3.3.1. ALUMINUM FOIL

Aluminum foil are obtained from Monier Sdn.Bhd, Shah Alam. Their respective properties can be found in the product datasheet in the appendix.

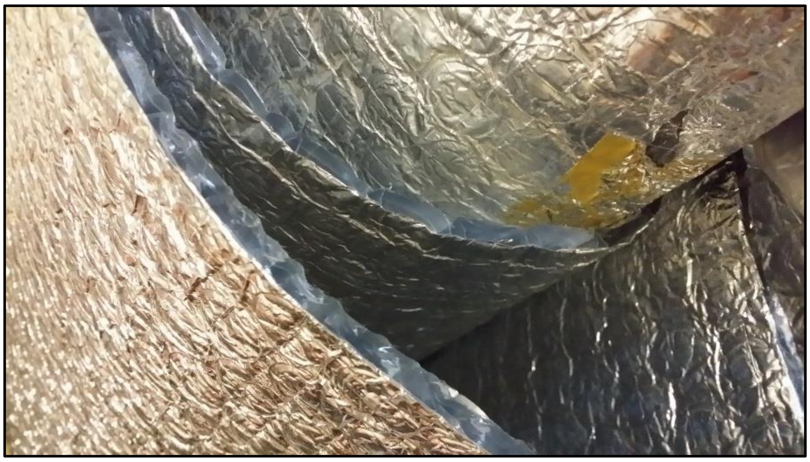


Figure 3-2 *Aluminum foil*

3.3.2. STONE WOOL

Stone wool is obtained from ROCKWOOL Malaysia Sdn Bhd. According to the product datasheet, the 50mm of stone wool blanket, it has nominal density of 50kg/m^3 and thermal conductivity of 0.035W/mK. The other properties of rockwool can be found in its product datasheet in the appendix.

Figure 3-3 *Rockwool*

3.3.3. LOW DENSITY POLYETHYLENE (LDPE)

Low density polyethylene (LDPE) is obtained from Lotte Chemical Titan(M) Sdn Bhd. According to the product datasheet, the melting point of LDPE is in between 160°*C* and *240°C.* Besides, it has density of 0.920g/cm^3, thermal conductivity of 0.33~0.34W/mK and tensile strength of 120kg/cm^2 at yield. The other properties of LDPE can be found in its product datasheet in the appendix.

Figure 3-4 *Low density polyethylene (LDPE)*

3.3.4. KAPOK FIBRE

Kapok Fibre is obtained from Portal Perak. It has thermal conductivity of 0.03~0.04W/mK and low density of 0.29g/cm^3 (Cui et al., 2009).

Figure 3-5 *Kapok Fibre*

3.3.5. MAEROGEL

Maerogel is obtained from Gelanggang Kencana Sdn Bhd. Maerogel has low apparent density of 0.03g/cm^3 and low thermal conductivity of 0.03W/m.K (Rajalingam, 2013; Zulkifli et al., 2014)

Figure 3-6 *Maerogel*

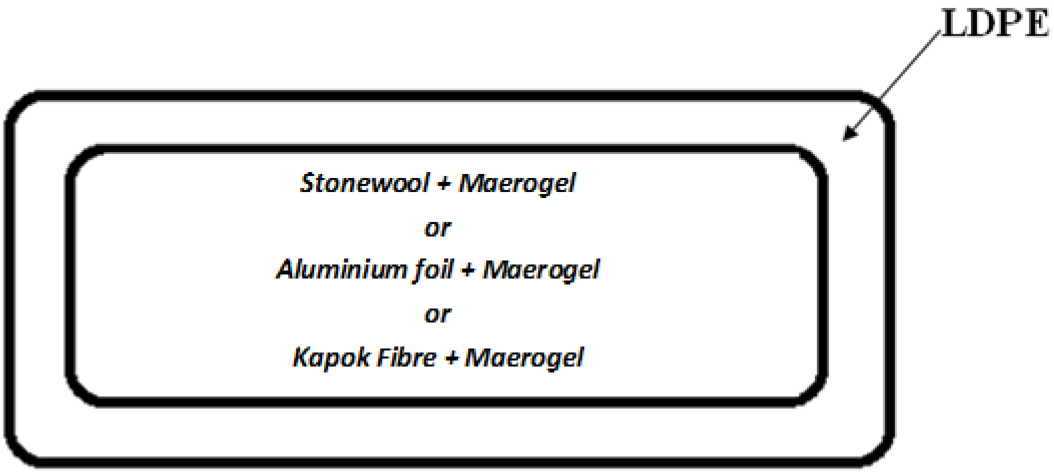


Figure 3-7 *Composite roof insulation samples***.**

Figure 3-8 Processes of samples preparation by using hot compression machine.

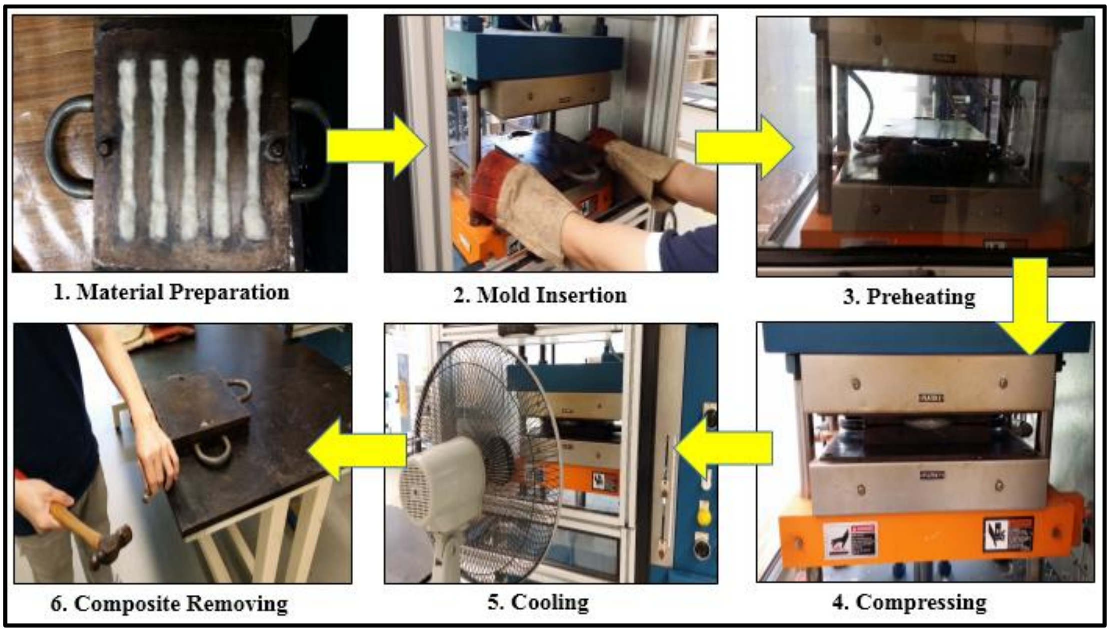


Figure 3-8 *Processes of samples preparation*

Procedure of LDPE layers preparation:

1) Thin layer of wax is applied on the surface of mold to ease the samples removing from mold.
2) LDPE pellets are weighed and put into the mold cavity.
3) The top cover of mold is closed and the mold is then inserted into the compression molding machine.
4) The mold is preheat at 160°C for 5 minutes and compressed at 120 ton force pressure for 25 minutes.
5) Air cooling and water cooling system are turned on.
6) The mold is cooled down until it reached the temperature of 80°C.
7) The mold is removed from the machine.
8) The completed LDPE layers are removed from the mold.
9) Steps 1 to 8 are repeated to produce 6 sets of LDPE layers.

The prepared LDPE layers are in dog bone shape as shown in the **Figure 3-9**.

Figure 3-9 *Dog-bone shape LDPE layers*

Procedure of composite roof insulation samples preparation:

1) Thin layer of wax is applied on the surface of mold to ease the samples removing from mold.
2) One set of LDPE layers is inserted into the mold cavity.
3) Aluminium foil are cut into dog-bone shape in accordance with ASTM D638 Type 1 which are then weighed and put onto the LDPE layers.
4) Maerogel powder are weighed and put onto the aluminium foil.
5) Another set of LDPE layers is put into the mold cavity.
6) The top cover of mold is closed and the mold is then inserted into the compression molding machine.
7) The mold is preheat at 160°*C* for 5 minutes and compressed at 120 ton force pressure for 25 minutes.
8) Air cooling and water cooling system are turned on.
9) The mold is cooled down until it reached the temperature of 80°*C*.
10) The mold is removed from the machine.
11) The completed composite roof insulation samples are removed from the mold.
12) Steps 1 to 8 are repeated to by replacing aluminium foil with stone wool/ kapok fibre.

3.4. TEST METHODOLOGY

3.4.1. THERMAL CONDUCTIVITY TEST

Thermal conductivity test are conducted for all types of composite roof insulation samples by using TCi Thermal Conductivity Analyzer. TCi Thermal Conductivity Analyzer provide simple, highly accurate thermal characterization for lab, quality control and production environments. This instrument has broad testing capabilities of 0.0 to 220 W/mK in a wide range temperature from -50°*C* to 200°*C*.

General procedure of thermal conductivity test by using TCi Thermal Conductivity Analyzer:

1) The samples need to be tested are prepared and clean with delicate task wipers.
2) Three drops of deionized water (contact agent) are spread on the sensor surface.
3) Pyrex (reference material) is gently placed on the sensor. It must be handled with gloves to prevent thermal contamination.
4) The weight is placed on the pyrex carefully to prevent any damage that could cause to the sensor chip.
5) Reference test is run and stopped when 5 consecutive readings which is within the acceptable range is achieved.
6) The weight and the pyrex are removed.
7) Both the sensor and weight are cleaned by using delicate task wipers.
8) Three drops of deionized water are spread on the sensor surface.
9) Aluminum foil composite sample is gently placed on the sensor. It must be handle with gloves to prevent thermal contamination.
10) The weight is placed on the sample carefully to prevent any damage that could cause to the sensor chip.
11) The thermal conductivity test is run and stopped when 10 consecutive valid readings is recorded by the instrument.

12) The weight and sample are removed.

13) Step 7 to step 12 are repeated by replacing aluminium foil composite sample with stone wool composite and kapok fibre composite sample.

3.4.2. TENSILE TEST

Tensile tests are conducted for all types of composite roof insulation samples at room temperature of 25°C by using the Universal Testing Machine. The samples are tested for tensile strength based on ASTM standard D638 Type 1. The dimension of the specimen is presented in **Figure 3-10** and **Table 3-2.**

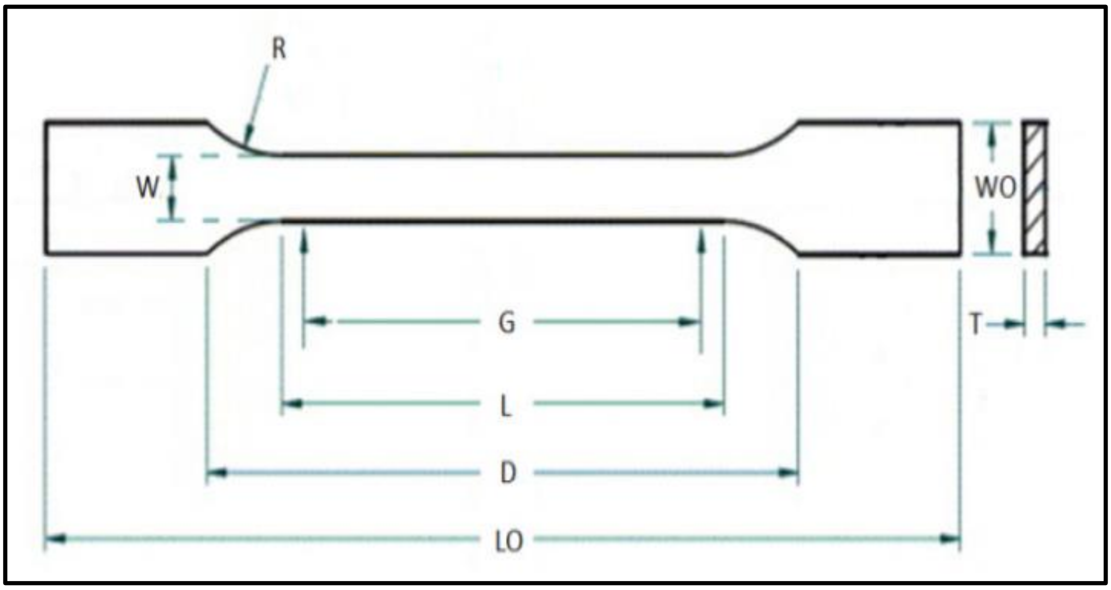


Figure 3-10 *ASTM Type 1 specimen dimension (dog-bone shape).*

*Area = 2509 mm^2 (drawn and taken from AutoCad)

Dimensions	Length (mm)
W - Width of narrow section	13 ± 0.5
L - Length of narrow section	57 ± 0.5
WO - Width overall, min	19 ± 6.4
LO - Length overall, min	165
G - Gage length	50 ± 0.25
D - Distance between grips	115 ± 5
R - Radius of fillet	76 ± 1
T - Thickness	7 or under

Table 3-2 *ASTM Type 1 specimen dimension (dog-bone shape).*

Procedures of tensile test:

1) First of all, the crosshead of the Universal Testing Machine is adjusted to an appropriate height so that the composite roof insulation samples can be placed properly.
2) Composite roof insulation sample is placed inside the grips.
3) The laser sensor is switched on followed by some adjustment of the tape so that the gap between the two tapes is exactly “10.00” as displayed by the sensor.
4) The position of the grips are set to zero.
5) The machine is switched on and the sample is started to be pulled.
6) The machine will be stopped automatically once the sample is failed.
7) All the data such as tensile strength and tensile modulus are recorded.

3.4.3. SIMULATION TEST USING AUTODESK ECOTECT

The purpose of simulation using Autodesk Ecotect is to determine the effectiveness of the composite roof insulation materials. To perform this, three experimental houses are modelled by following the dimension of the thermal insulated house that located in Monier Sdn Bhd which is a manufacturer and supplier of roof products at Shah Alam. Particularly, the walls of the experimental houses are installed with 100m thick of Styrofoam to prevent any lateral heat transfer through the wall. This is done to ensure that the roofs accountable for 100% of heat gain of the houses.

Figure 3-11 *Experimental houses & wall of experimental houses that installed with 100mm thick Styrofoam in Monier Sdn Bhd, Shah Alam.*

These three experimental houses which are in the dimension of 3m width, 5m length and 3m height are modelled in Autodesk Ecotect as shown in **Figure 3-12**. The details and materials assigned to the experimental houses' model are shown in **Table 3-3** whereas the cross section of the attic part of the roof and the wall are illustrated in **Figure 3-13** and **Figure 3-14** respectively.

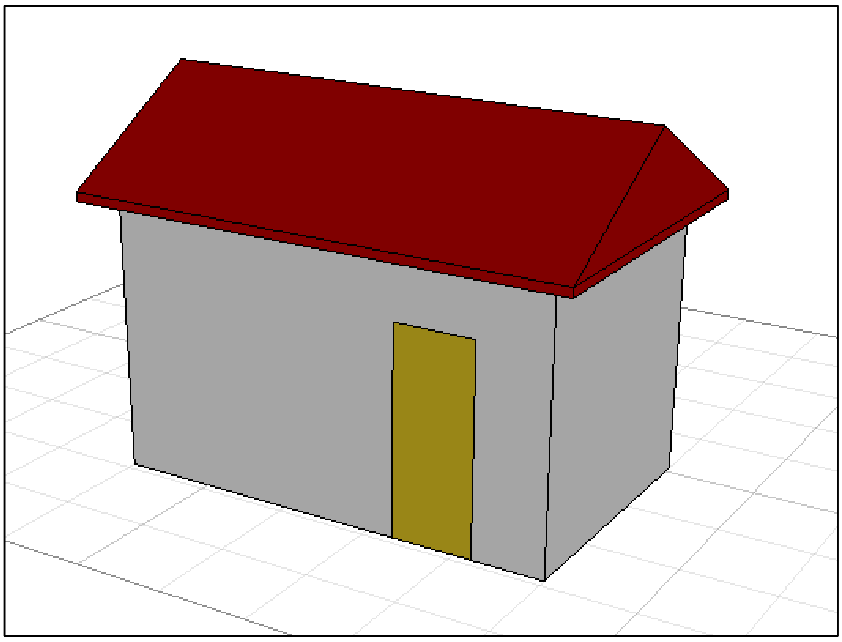


Figure 3-12 *Modelled experimental house by using Ecotect.*

The details and materials assigned to the modelled experimental house are as followings:

Object	Materials & Details
Dimension	• 3m(width) X 5m(length) X 3m(height)
Wall	• 130 mm Brick plaster wall (100mm brick with 10mm plaster either side. • 100mm thick high density polystyrene foam at inner layer of wall
Door	• 40mm thick Hollow_core plywood door
Ceiling	• Plasterboard ceiling • Composite roof insulation materials
Roof	• Clay tiled roof • 30° pitched shaped roof • 1 feet overhang

Table 3-3 *Details and materials assigned to the experimental house's model*

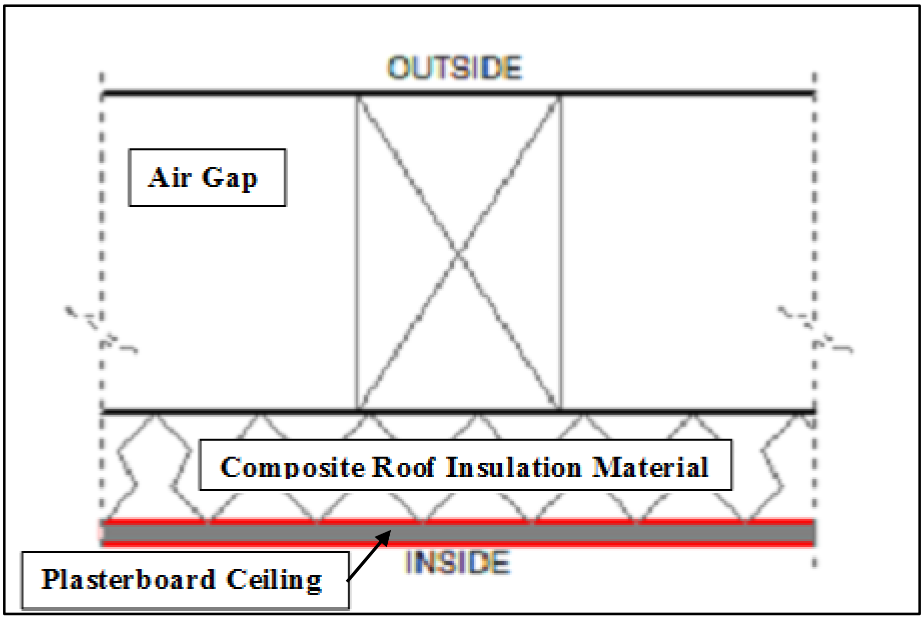


Figure 3-13 *Cross-section of the roof attic*

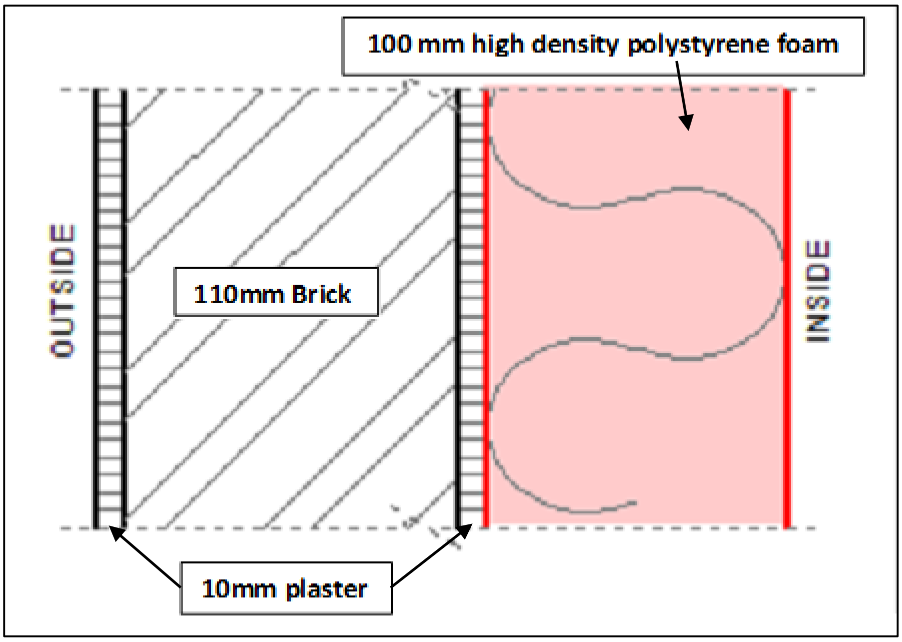


Figure 3-14 *Cross-section of wall.*

In the simulation by using Autodesk Ecotect, the thermal performance of the three composite roof insulation material are tested, they are:

i) Sample A : Aluminum Foil + LDPE + Maerogel

ii) Sample B : Stone Wool + LDPE + Maerogel

iii) Sample C : Kapok Fibre + LDPE + Maerogel

These three types of composite roof insulation material together with their tested thermal conductivity results obtained from lab test are assigned to the insulation layer of the ceiling of the experimental houses in Autodesk Ecotect.

The main output of simulation is to generate the hourly temperature profile of the three modelled experimental houses for 5 days, from 9am to 5pm. The hourly temperature profile will demonstrate the indoor temperature and outdoor temperature of the experimental houses. The indoor-outdoor temperature difference graphs are plotted and analysed to determine the effectiveness of the composite roof insulation materials.

3.5. KEY MILESTONES

There are several key milestones in my final year project. They are very important as each of them has to be completed in advance before we can go further or move into the next stages in the project. They are:

1) Calibration of experimental houses
2) Understood the experiment method
3) Completion of samples preparation
4) Completion of tensile & flexural test
5) Completion of result analysis & discussion
6) Complete study

3.6. GANTT CHART

NO.	Project Flow/Task (FYP 1)	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		22/9/2014-5/10/2014		6/10/2014-19/10/2014		20/10/2014-2/11/2014		3/11/2014-16/11/2014		17/11/2014-30/11/2014		1/12/2014-14/12/2014		15/12/2014-26/12/2014	
1	**CONFIRMATION OF PROJECT TITLE** • Consultation with UTP supervisor.														
2	**PRELIMINARY RESEARCH WORKS** • Reading and study on related journals.														
3	**LITERATURE REVIEW** • Review other researchers' works and findings. • Prepare an comprehensive and up-to-date literature review														
4	**SURVEY FOR TOOLS & EQUIPMENT** • Understand the functions of tools and equipment required.														
5	**UNDERSTANDING OF THE INSULATION MATERIALS** • Study deeply about the properties of each type of insulation materials														
6	**STUDY THE EXPERIMENT SETUP** • Study deeply into the procedures and method of experiments.														
7	**CALIRATION OF EXPERIMNETAL HOUSES** • Visit the experimental house. • Calibration of thermocouples.														
8	**UNDERSTOOD THE EXPERIMENT METHOD**														
9	**PROPOSAL DEFNCE**														
10	**INTERIM REPORT** • Prepare a well written interim report • Submission of interim repot														
11	**END OF FYP 1**														

Key Milestones **Duration** **END**

NO.	Project Flow/Task (FYP 2)	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		22/9/2014-5/10/2014		6/10/2014-19/10/2014		20/10/2014-2/11/2014		3/11/2014-16/11/2014		17/11/2014-30/11/2014		1/12/2014-14/12/2014		15/12/2014-26/12/2014	
1	**SAMPLES PREPARATION** • Preparation of composite roof insulation materials														
2	**COMPLETEION OF SAMPLES PREPARATION**														
3	**MECHANICAL PROPERTIES TEST** • Conduct tensile and flexural test of composite roof insulation materials														
4	**COMPLETION OF MECHANICAL TEST**														
5	**THERMAL ANALYSIS (LAB)** • Conduct thermal conductivity test in lab by using thermal analyzer														
6	• **Simulation Using Autodesk Ecotect**														
7	**RESULT ANALYSIS & DISCUSSION** • Calculate the thermal conductivity of each types of composite roof insulation samples Analyze the result and write a detail discussion														
8	• **COMPLETION OF RESULT ANALYSIS & DISCUSSION**														
9	**FINAL REPORT** Prepare a well written final report.														
10	• **END OF FYP**														

Key Milestones **Duration** **END**

CHAPTER 4
RESULT & DISCUSSION

4.0 RESULT AND DISCUSSION

4.1. COMPOSITE ROOF INSULATION SAMPLES

The completed composite roof insulation samples by using compression molding are labelled and shown in **Figure 4-1, Figure 4-2** and **Figure 4-3**. Also, their dimensions and weight are measured to calculate their respective volume and density. Their physical properties are tabulated in **Table 4-1**.

Figure 4-1 *Aluminum foil + LDPE + Maerogel composite roof insulation samples.*

Figure 4-2 *Stone Wool + LDPE + Maerogel composite roof insulation samples.*

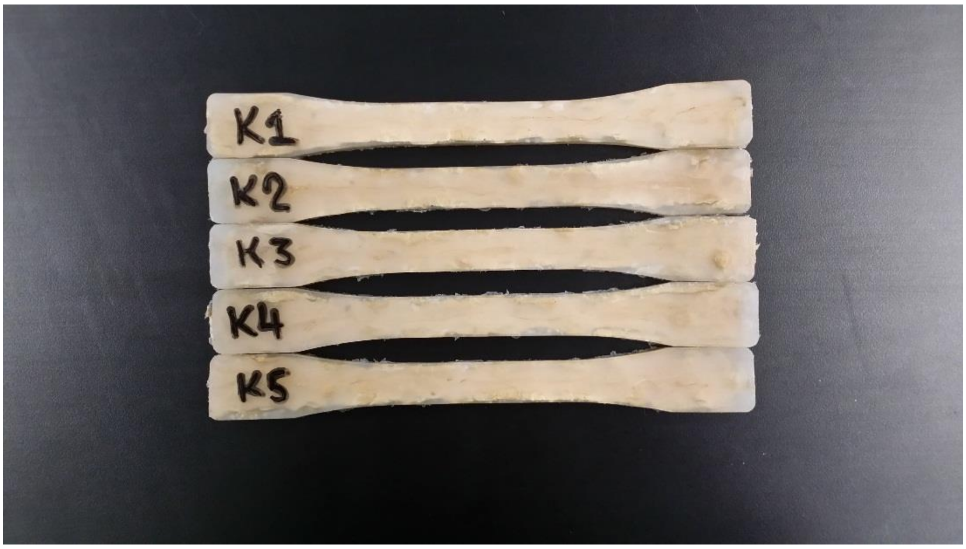


Figure 4-3 *Kapok Fibre + LDPE + Maerogel composite roof insulation samples.*

Sample	Label	Mass (g)	Thickness (mm)						Volume m3	Density (kg/m3)	
			1	2	3	4	5	Average			
Aluminum Foil + LDPE + Maerogel	A1	8.571	3.845	3.847	3.824	3.835	3.829	**3.836**	9624.52	890.54	**895.22**
	A2	8.585	3.831	3.845	3.847	3.852	3.838	**3.843**	9641.08	890.46	
	A3	8.61	3.811	3.793	3.786	3.789	3.811	**3.798**	9529.18	903.54	
	A4	8.542	3.801	3.802	3.789	3.792	3.78	**3.793**	9516.14	897.63	
	A5	8.576	3.811	3.806	3.824	3.858	3.819	**3.824**	9593.41	893.95	
Stone Wool + LDPE + Maerogel	S1	8.965	3.826	3.848	3.842	3.837	3.835	**3.838**	9628.54	931.09	**933.26**
	S2	8.977	3.815	3.831	3.834	3.827	3.831	**3.828**	9603.45	934.77	
	S3	9.122	3.905	3.892	3.893	3.91	3.898	**3.900**	9784.10	932.33	
	S4	9.044	3.856	3.894	3.874	3.856	3.821	**3.860**	9685.24	933.79	
	S5	8.989	3.829	3.815	3.866	3.826	3.837	**3.835**	9621.01	934.31	
Kapok Fibre + LDPE + Maerogel	K1	8.617	3.81	3.825	3.837	3.797	3.798	**3.813**	9567.82	900.62	**905.50**
	K2	8.628	3.786	3.783	3.767	3.739	3.788	**3.773**	9465.45	911.53	
	K3	8.713	3.835	3.81	3.78	3.796	3.838	**3.812**	9563.81	911.04	
	K4	8.704	3.863	3.848	3.832	3.862	3.849	**3.851**	9661.66	900.88	
	K5	8.629	3.794	3.812	3.835	3.798	3.795	**3.807**	9551.26	903.44	

Table 4-1 *Physical properties of composite roof insulation samples.*

4.2. THERMAL CONDUCTIVITY TEST

Thermal conductivity tests are conducted to determine the thermal properties of the composite roof insulation samples. The results are tabulated in **Table 4-2**. Besides, the thermal conductivity of the raw materials are listed in **Table 4-3**.

Sample	Label	Thermal Analyzer Code	Thermal Conductivity, k (W/mK)		Specific Heat Capacity (J/kg/K)	
Aluminium Foil + LDPE + Maerogel	A1	126	0.857	**0.824**	755.496	**749.659**
	A2	127	0.729		733.186	
	A3	122	0.864		756.636	
	A4	123	0.758		738.594	
	A5	128	0.914		764.384	
Stone Wool + LDPE + Maerogel	S1	114	0.719	**0.668**	731.406	**720.453**
	S2	131	0.631		713.13	
	S3	116	0.622		711.142	
	S4	118	0.767		740.224	
	S5	119	0.6		706.362	
Kapok Fibre + LDPE + Maerogel	K1	102	0.502	**0.485**	682.55	**677.529**
	K2	104	0.452		668.812	
	K3	105	0.562		697.374	
	K4	106	0.435		664.032	
	K5	108	0.473		674.878	

Table 4-2 *Thermal properties of composite roof insulation materials.*

Material	Thermal Conductivity W/m.K
Aluminum Foil	0.4
Stone Wool (50mm blanket)	0.034~0.036
Low Density Polyethylene (pellet)	0.33~0.34
Kapok Fibre	0.03~0.04
Maerogel (powder)	0.03

Table 4-3 *Thermal properties of raw materials from product datasheets & internal sources.*

As shown in the **Table4-2,** kapok fibre +LDPE + maerogel has lowest thermal conductivity which is **0.485W/mK** while aluminium foil composite has the highest thermal conductivity which is **0.824W/mK**. Generally, thermal conductivity of a material is referring to the ability of a material to conduct heat. Heat transfer occurs at higher rate across the material of higher thermal conductivity than the lower thermal conductivity materials. It mean that aluminium foil composite is better in conducting heat than kapok fibre composite. In other words, kapok fibre composite is the best composite roof insulation materials among the three composites in insulating heat from outdoor to indoor of buildings.

However, when comparing the thermal conductivity of the composite materials with the raw materials, it is obvious that the composite materials have higher thermal conductivity. The possible reason is due to the weak interfacial bonding between the materials with low density polyethylene (LDPE) which is act as the binding material of the composites. As shown in **Table 4-3**, LDPE pellets (raw material) has thermal conductivity of **0.33W/mK**. Although we incorporate LDPE with other materials with lower thermal conductivity (both kapok fibre and maerogel have thermal conductivity as low as **0.03W/mK**), instead of reducing the thermal conductivity, it goes the other way.

4.3. TENSILE TEST

Tensile tests are conducted to determine the tensile properties of the composite materials. The tensile strengths of the composite materials are tabulated in **Table 4-4** while the tensile strengths of the raw materials are listed in **Table 4-5**. Besides, the stress-strain graphs of each composites materials are shown in the **Appendix**.

Composite Sample	Tensile Strength (MPa)
Aluminum+LDPE+Maerogel	2.456
Stone wool+LDPE+Maerogel	2.438
Kapok Fibre+LDPE+Maerogel	2.411

Table 4-4 *Tensile strength of composite samples.*

Material	Tensile Strength MPa
Aluminium Foil	350~400MD or 100~200CD
Stone Wool	N.A
Low Density Polyethylene	12
Kapok Fibre	N.A
Maerogel	0.016

Table 4-5 *Tensile Strength of raw materials.*

As shown in **Table 4-4**, the tensile strength of aluminium foil composite is slightly higher which **2.456Mpa**, followed by is stone wool composite and kapok fibre composite which have tensile strength of **2.438MPa** and **2.411MPa** respectively. In sum, all the composite samples share about the same tensile strength. The main reason is due to all of them has high percentage of matrix which is 94% of LDPE. As mention earlier, kapok fibre and maerogel are very brittle and fragile. In addition, they have very low tensile strength. It can be concluded that the tensile strength of the composites are come from the tensile strength of the matrix (LDPE) itself. Therefore, the tensile properties of the composites are dominated by the matrix and these composite samples has about the same tensile strength.

4.4. SIMULATION USING AUTODESK ECOTECT

4.4.1. BASELINE MODEL

A baseline model of experimental house (3mX5mX3m) has been modelled and designed using Autodesk Ecotect as shown in **Figure 4.4**.

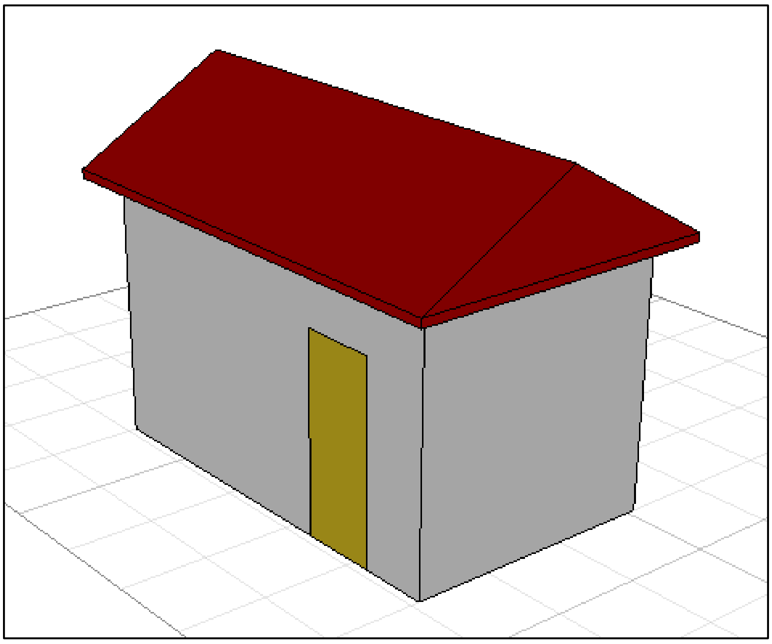


Figure 4-4 *Baseline model of experimental house.*

In this baseline model, there isn't any insulation material added on top of the ceiling board. The details and materials assigned to this baseline model are stated in **Table 4-6**. Besides, the cross section of the attic part of the roof and the wall are illustrated in **Figure 4-5** and **Figure 4-6**.

Object	Materials & Details
Wall	• 130 mm Brick plaster wall (100mm brick with 10mm plaster either side. • 100mm thick high density polystyrene foam at inner layer of wall
Door	• 40mm thick Hollow core plywood door
Ceiling	• Plasterboard ceiling
Roof	• Clay tiled roof • 30° pitched shaped roof • 1 feet overhang

Table 4-6 *Details and materials assigned to baseline model*

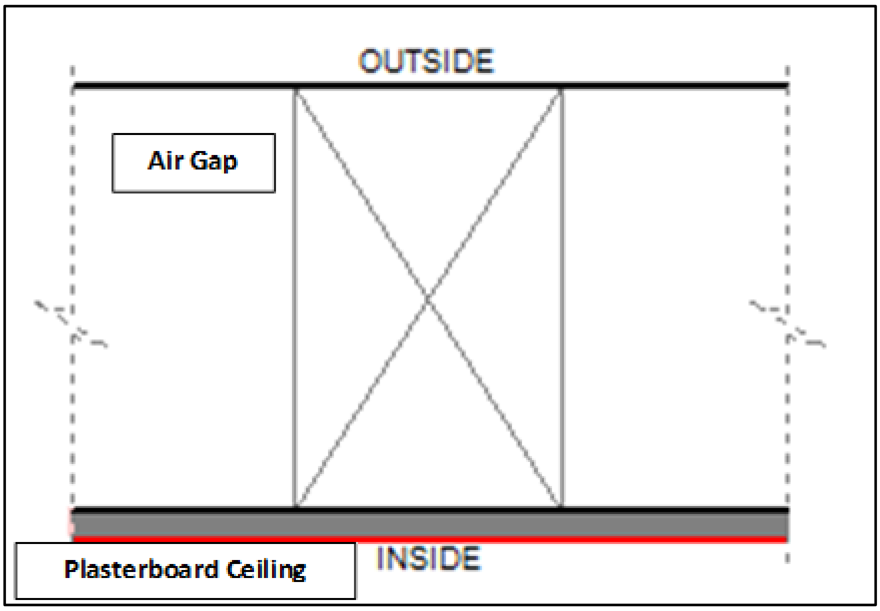


Figure 4-5 *Cross-section of the roof attic of baseline model.*

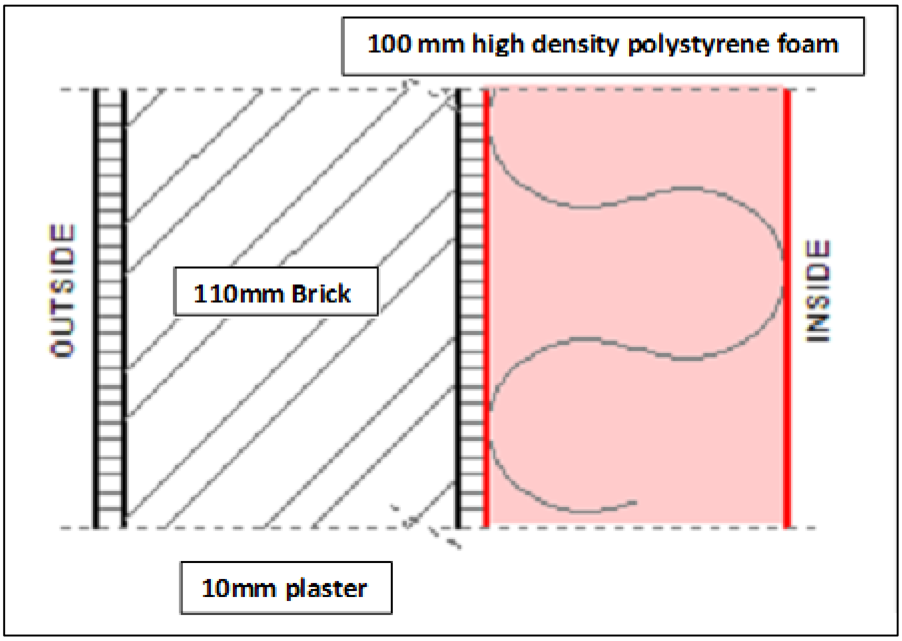


Figure 4-6 *Cross-section of the wall of baseline model.*

The hourly temperature profile of the baseline model on 23 February 2015 has been generated as shown in **Figure 4-7**.

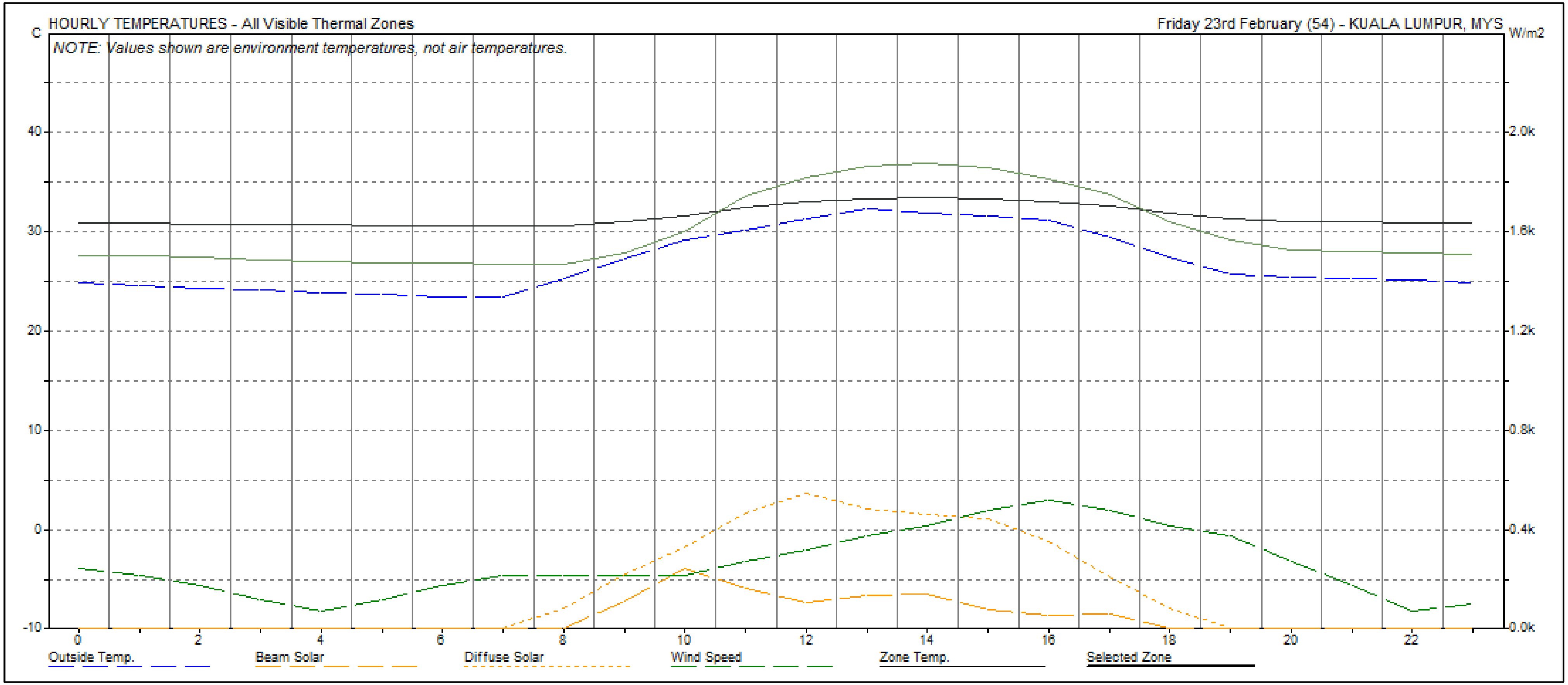


Figure 4-7 *Hourly temperature profile of baseline model of experimental house on 23 February 2015.*

Figure 4-7 illustrated the hourly temperature profile of the baseline model of experimental house on 23 February 2015. As shown in the graph, the blue dotted line indicate the outdoor temperature while the green line and grey line indicate the temperature in roof attic and indoor of the experimental house respectively. Surprisingly, the outdoor temperature is obviously lower than the indoor temperature. This might be due to the absent of insulation layer above the ceiling board and poor ventilation of the experimental house.

Indeed, with a good insulation roofing system, it was expected that the indoor temperature is lower than the outdoor temperature to provide adequate thermal comfort to the occupants that staying within the unit. Hence, it was expected that the three modelled experimental houses installed with three different layer of composite roof insulation materials at the roof attic are able to provide a thermal comfortable indoor living environment for the occupants.

4.4.2. HOURLY TEMPERATURE GRAPH OF COMPOSITES

Three thermal insulated experimental houses are modelled exactly with the same dimensions and building materials as baseline model. However, in the thermal insulated experimental houses, there is composite roof insulation layer added at the ceiling as shown in **Figure 4-8**. The composite roof insulation layers are referred to:

a) Aluminum Foil + LDPE + Maerogel
b) Stone Wool + LDPE + Maerogel
c) Kapok Fibre + LDPE + Maerogel

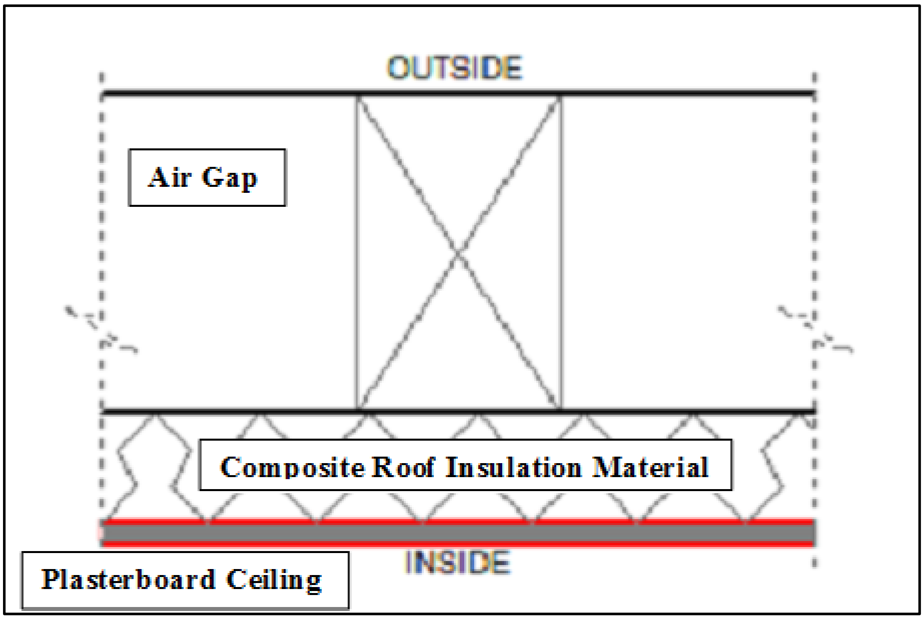


Figure 4-8 *Cross section of the roof attic of thermal insulated experimental house.*

Besides, the important properties need to be assigned are respective density, specific heat capacity and thermal conductivity that had been listed in **Table 4-1** and **Table 4-2** as shown in **Figure 4-9**.

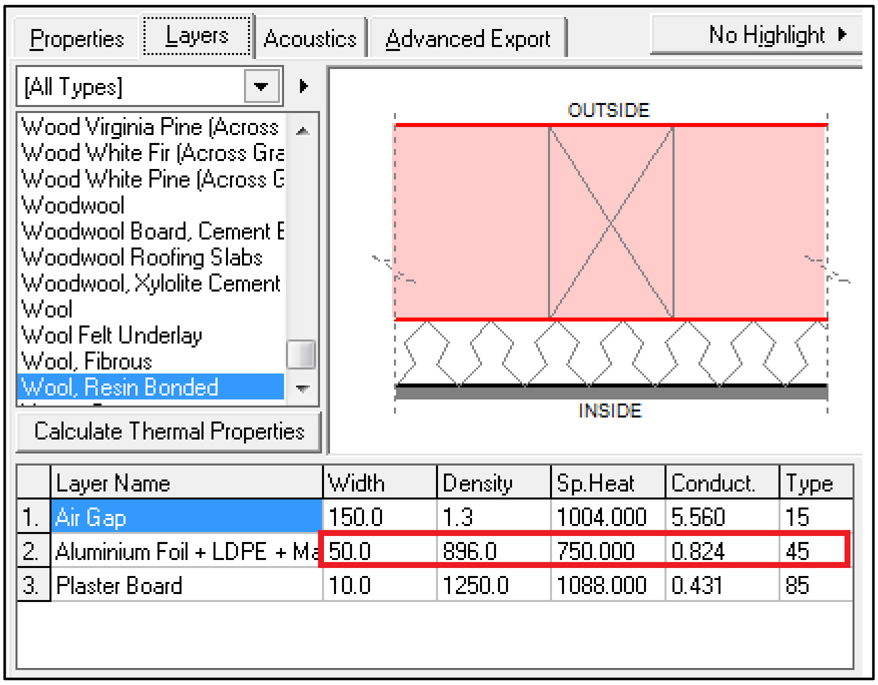


Figure 4-9 *Composite roof insulation layer in Autodesk Ecotect.*

In the simulation by using Autodesk Ecotect, the hourly temperature graph including the outdoor temperature and indoor temperature of the thermal insulated experimental house for 5 days consecutively (1st of January to 5th of January) from 9am to 5pm is calculated by Ecotect and plotted in **Figure 4-10**, **Figure 4-11** and **Figure 4-12**. The main reason of selecting only the readings between 9am to 5pm is because they are the hours between sunrise and sunset where the outdoor temperature and indoor temperature are highest. During these hours, the insulation properties of the roof is significant in insulating heat from outdoor to indoor to ensure indoor thermal comfort for the occupants.

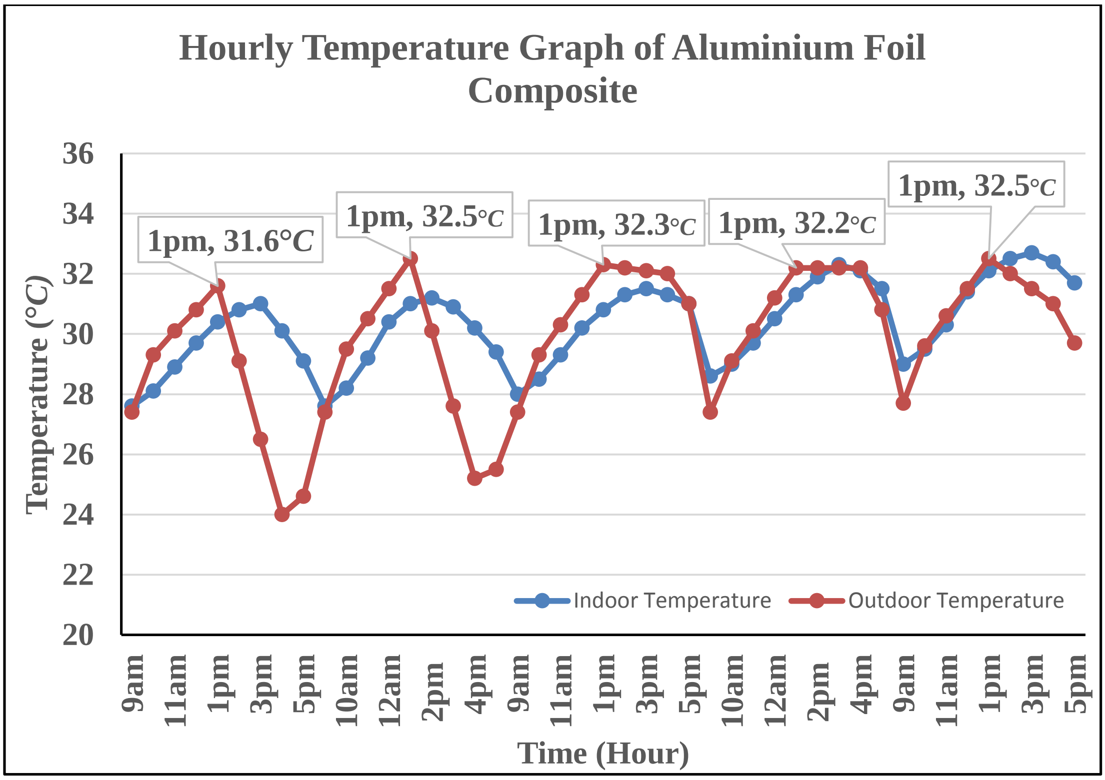


Figure 4-10 *Hourly temperature graph of Aluminum Foil composite roof insulation.*

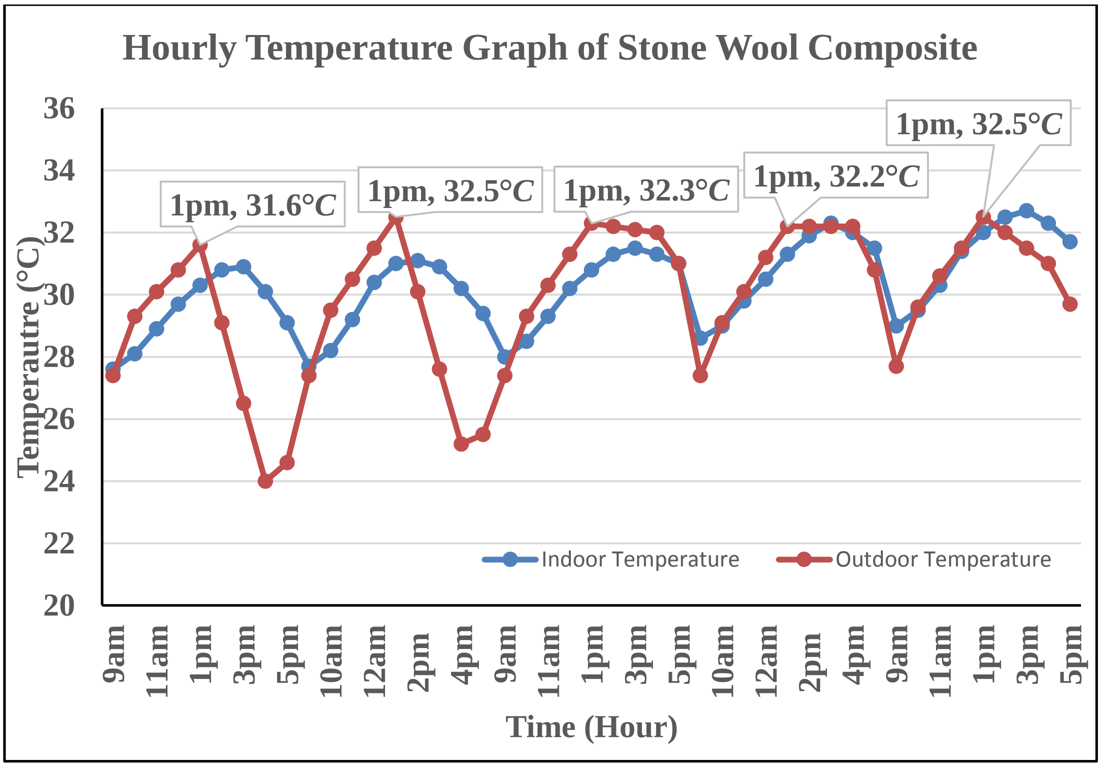


Figure 4-11 *Hourly temperature graph of Stone Wool composite roof insulation.*

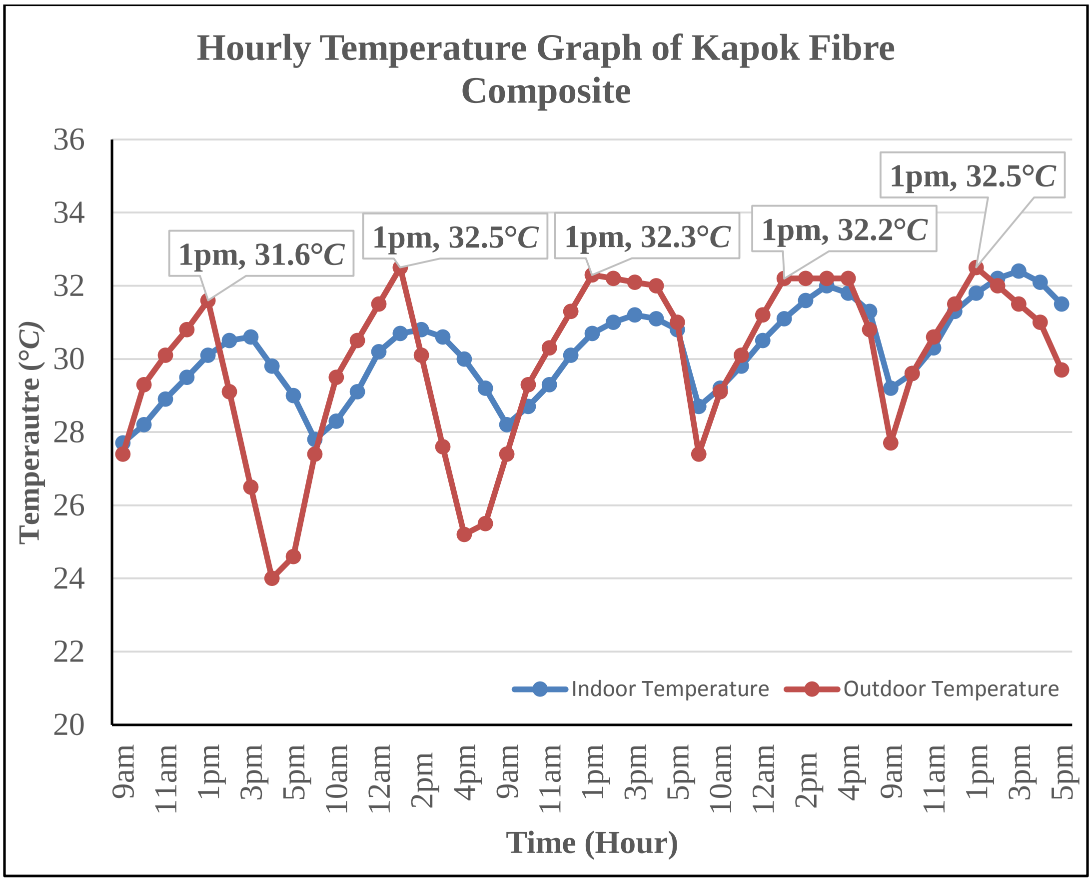


Figure 4-12 *Hourly temperature graph of Kapok Fibre composite roof insulation.*

Generally, the walls of most of the houses and low rises buildings in Malaysia are built of concrete block wall or red sandstone wall which has high thermal mass. Hence, after sunrise, both the outdoor temperature and indoor temperature will be increased but the indoor temperature will remain lower than the outdoor until the outdoor temperature had reached its peak. Usually, the hottest hour of the day in Malaysia occurs between 1pm and 3pm due to thermal lag. As shown in the graphs from **Figure 4-10** to **Figure 4-12**, all of the modelled experimental houses has the same outdoor temperature. Also, the hottest hour of each day, from 1st of January to 5th of January occur at the same time which is at 1pm in the afternoon. Besides, the hottest indoor temperature occur at between 2pm to 4pm.

Besides, it can be observed that after the hottest peak hour at 1pm, the outdoor temperature start to reduce and the indoor temperature continue to increase until they reach their peak at between 2pm to 4pm due to thermal lag. Furthermore, after 1pm, the indoor temperature become higher than the outdoor temperature, this is due to the heat that radiated into the interior part of the house unable to escape easily as the ceiling of the roofs are insulated. Therefore, the cooling speed of the indoor is slower than the outdoor. This can be used to explain that the reason of the outdoor temperature is always cooler than the indoor temperature of our house at night.

Nevertheless, it also shown that all the indoor temperature during the hot hours of the day are below **34°*C*.** They does not exceeded the acceptable thermal comfort temperature limit for the occupants which is preferably to be lesser than 34°*C* *(Makaremi et al., 2012; Wijewardane & Jayasinghe, 2008). This mean* ***that all of the composite roof insulation samples are effective to maintain the indoor temperature of the house to below* 34°*C and ensure indoor thermal comfort for the occupants.***

4.4.3. HOURLY TEMPERATURE DIFFERENCE GRAPH OF COMPOSITES

In this section, the hourly temperature difference graph of the composites are calculated by subtracting the indoor temperature from outdoor temperature **(T_{out}-T_{in})**. The purpose of plotting the hourly temperature difference graph is to determine the thermal performance of the composite roof insulation materials. Generally, the higher the positive difference between the outdoor and indoor temperature at hottest hour of the day, the better the thermal performance of the roof insulation materials. The respective hourly temperature difference graph of the composite are plotted in **Figure 4-13**, **Figure 4-14**, and **Figure 4-15**. Also, the combination hourly temperature difference graph is plotted in **Figure 4-16**.

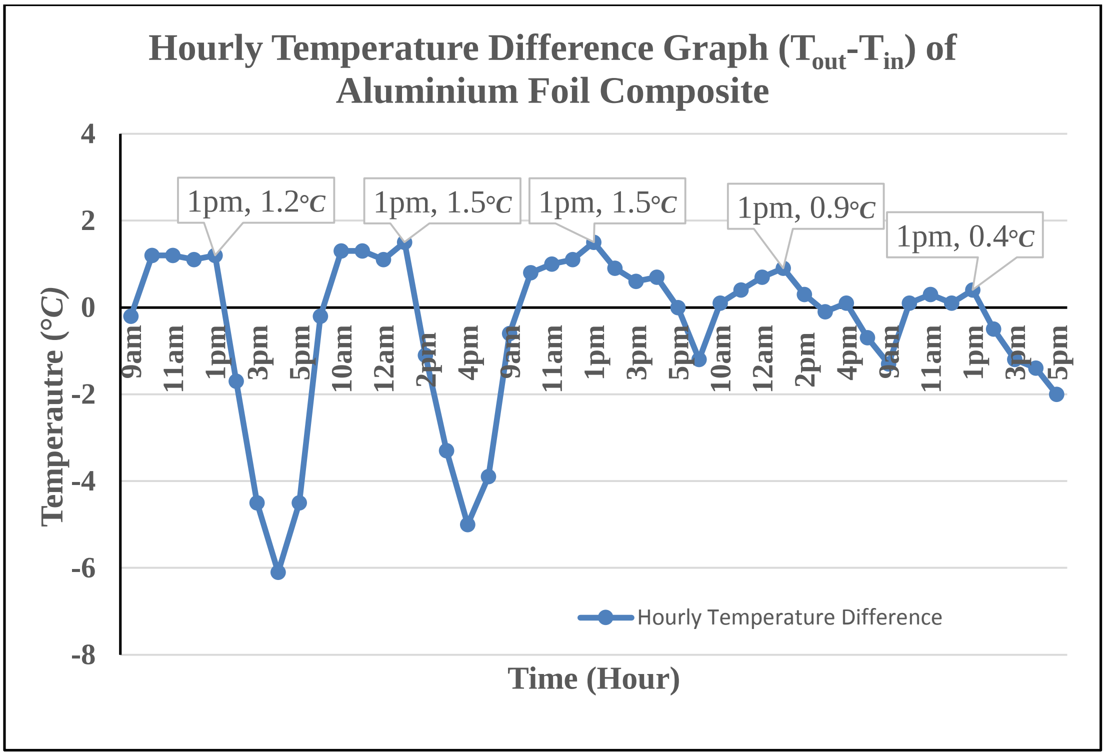


Figure 4-13 *Hourly temperature difference graph (T_{out}-T_{in}) of Aluminum Foil Composite.*

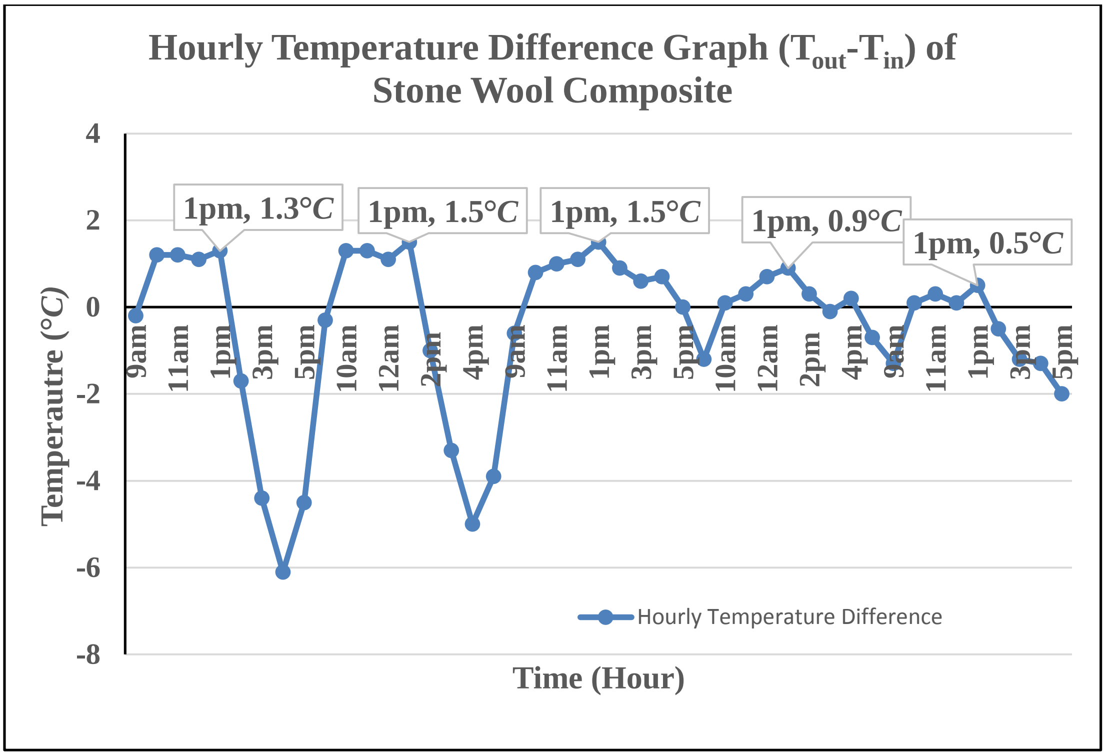


Figure 4-14 *Hourly temperature difference graph (T_{out}-T_{in}) of Stone Wool composite*

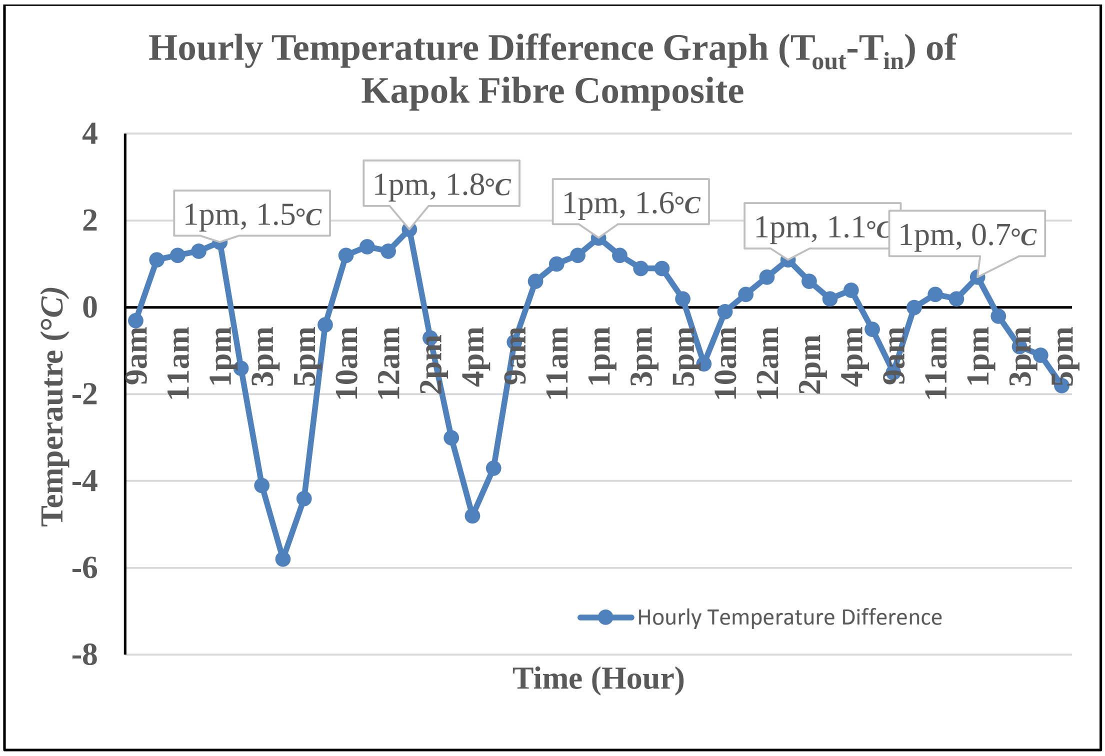


Figure 4-15 *Hourly temperature difference graph (T_{out}-T_{in}) of Kapok Fibre Composite.*

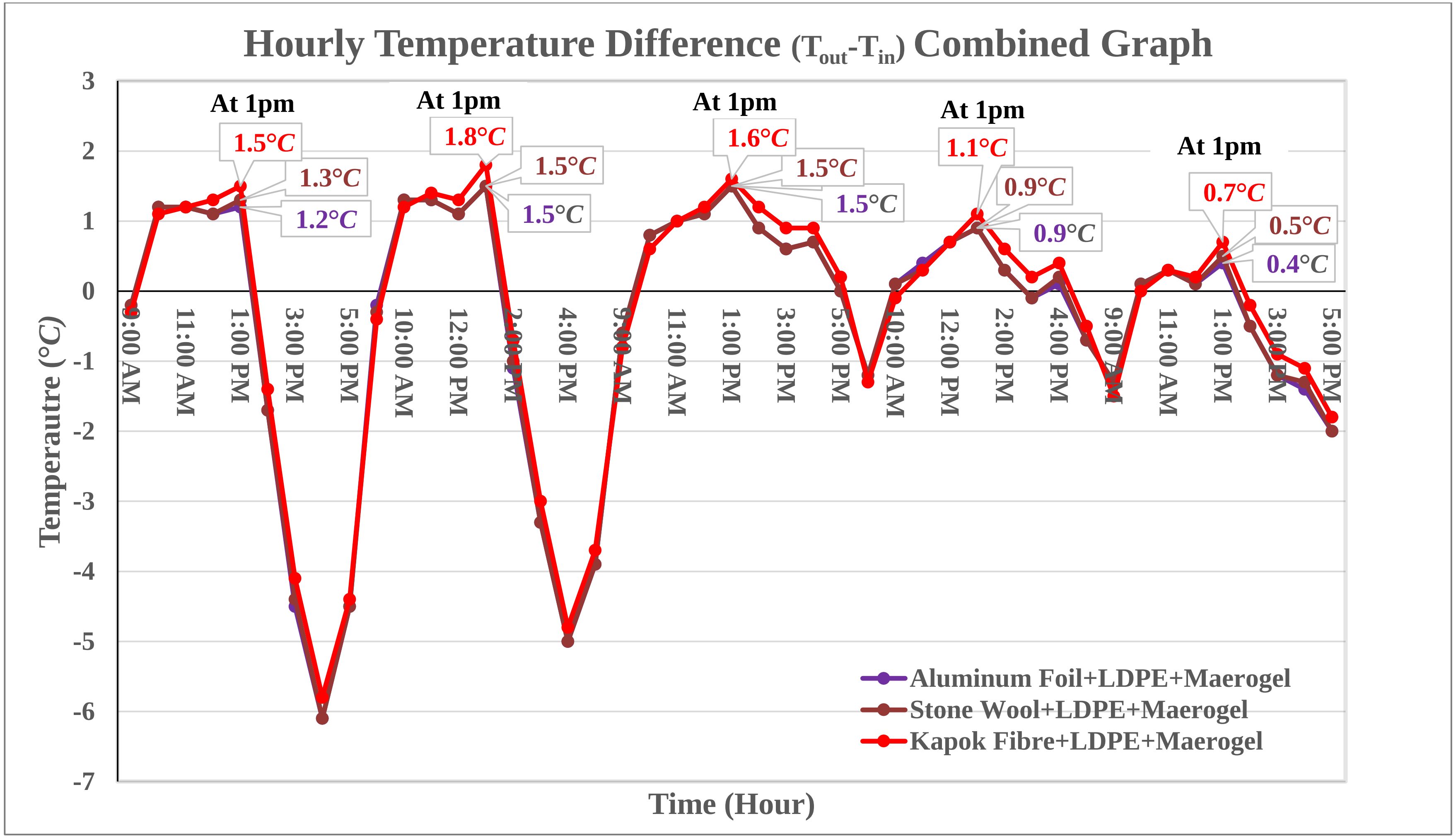


Figure 4-16 *Hourly temperature difference (T_{out}-T_{in}) combined graph.*

As shown in **Figure 4-13** to **Figure 4-15,** all types of composite roof insulation experimental houses has highest temperature difference of outdoor and indoor at 1pm. However, as shown in **Figure 4-16**, the modelled house installed with kapok fibre + LDPE + maerogel has higher temperature difference at peak hour on the 1st day which is **1.5°*C*** whereas aluminium foil composite and stone wool composite have temperature difference of **1.0°*C and 1.3°C respectively*.** This means that kapok fibre composite perform better in insulating heat from outdoor to indoor. Whereas stone wool composite has about the same thermal performance as aluminium foil. This scenario remain the same for the next four days.

Besides, it is arguable that the thermal performance of these composite are about the same as the difference in temperature difference of the composites are in the range of **±0.3**. This mean that the thermal performance difference of the composite samples are not obvious. The possible reason is because the thermal properties is dominated by the matrix which is LDPE as all of them contains 94% of LDPE. This is indirectly supported by the fact that all of these composite has about the same tensile strength. Nevertheless, kapok fibre + LDPE + maerogel has lower thermal conductivity, slightly better thermal performance which is comparable to the common thermal insulation material, aluminium foil and stone wool. Also, it is a big new step to develop kapok fibre and maerogel as thermal insulation materials.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.0 CONCLUSION AND RECOMMENDATION

Building itself has own responsibility in heat reduction to ensure indoor thermal comfort for the occupants. Therefore, building insulation is very important which is normally referring to wall insulation and roof insulation. However, roof insulation is generally more critical than wall insulation as the roof is exposed to the hot sun directly during daylight hours. Besides, there is research gap in adopting kapok fibre and maerogel in the development of roof insulation materials which made up the most meaningful and challengeful part of this research.

In conclusion, **all the objectives of the research had been met**. It was found out that all of the composite roof insulation samples have about the same tensile strength because the tensile property of the composites are come from the matrix which is 94% of LDPE. Also, it can be concluded that **all of the composite roof insulation materials are effective in providing indoor thermal comfort to the occupants** as all of them are able to maintain the indoor temperature at below **34°*C which is the acceptable thermal comfort temperature limit*** *(Makaremi et al., 2012; Wijewardane & Jayasinghe, 2008).*

Beside, kapok fibre + LDPE + maerogel has **lowest thermal conductivity** which is **0.485 W/mK** among the three composites. This also explained why kapok fibre composites has **better thermal performance** than the other two composites in the simulation of thermal performance by using Autodesk Ecotect. However, it is arguable that there is only small difference in thermal performance between the composites. The possible reason is because the thermal properties of the composites are dominated by the matrix which is 94% of LDPE. Hence, it can be deduced that the ratio of the composition of the composite roof insulation samDifples is not optimum. In sum, the lowest thermal conductivity and slightly better thermal performance and shown by kapok fibre composites has proven that they are **the most effective** composite insulation materials and comparable to the two common insulation materials which is aluminium foil and stone wool. Nevertheless, incorporating kapok fibre and maerogel together with LDPE is a big new step to develop a new thermal insulation materials which is made of low density and low thermal conductivity of kapok fibre and maerogel which are brittle and fragile.

In the other hand, there are some suggested recommendations to improve the further research works. For instance, it is necessary to optimize the ratio of the composition of the composite roof insulation samples so that they would result in lower thermal conductivity and gives optimum thermal performance. Indeed, the percentage of kapok fibre and maerogel should be increased as these two materials are proven to have low thermal conductivity, low density and better thermal performance. Furthermore, I would like to recommend to conduct the thermal performance test in a normal scale house in Malaysia to validate the results of the simulation by using Autodesk Ecotect. Also, this research is recommended to be carried out in other location with different climate such as Oceanic climate which is accompanied with abundant precipitation throughout the year and Mediterranean climate which has four seasons in a year. Last but not least, it is recommended to conduct the experiment in fast developing countries such as China and India as this two countries have large population and the achieved research findings would be more convincing.

REFERENCES

1. Al-Homoud, D. M. S. (2005). Performance characteristics and practical applications of common building thermal insulation materials. *Building and Environment, 40*(3), 353-366. doi: 10.1016/j.buildenv.2004.05.013
2. Bektas Ekici, B., Aytac Gulten, A., & Aksoy, U. T. (2012). A study on the optimum insulation thicknesses of various types of external walls with respect to different materials, fuels and climate zones in Turkey. *Applied Energy, 92*, 211-217. doi: 10.1016/j.apenergy.2011.10.008
3. Borhani zarandi, M., Amrollahi Bioki, H., Mirbagheri, Z. A., Tabbakh, F., & Mirjalili, G. (2012). Effect of crystallinity and irradiation on thermal properties and specific heat capacity of LDPE & LDPE/EVA. *Appl Radiat Isot, 70*(1), 1-5. doi: 10.1016/j.apradiso.2011.09.001
4. Chung, B. Y., Hyeong, M. H., An, B. C., Lee, E. M., Lee, S. S., Kim, J.-H., . . . Cho, J.-Y. (2009). Flame-resistant kapok fiber manufactured using gamma ray. *Radiation Physics and Chemistry, 78*(7-8), 513-515. doi: 10.1016/j.radphyschem.2009.03.036
5. Cui, P., Wang, F.-M., Wei, A., & Zhao, K. (2009). The performance of kapok/down blended wadding. *Textile Research Journal*.
6. Dieng, M., Diagne, I., Fleur, B., Kane, A., Sow, M., & Sissoko, G. (2012). Study of Heat Transfer in a Kapok Material from the Convective Heat Transfer Coefficient and the Excitation Pulse of Solicitations External Climatic.
7. Energy Efficiency (26 February 2015). Retrieved from http://www.amarr.com/residential/before_you_buy/energy_efficiency
8. Hussein, I., Rahman, M. H. A., & Maria, T. (2009). *Field studies on thermal comfort of air-conditioned and non air-conditioned buildings in Malaysia.* Paper presented at the Energy and Environment, 2009. ICEE 2009. 3rd International Conference on.
9. Jayasinghe, M., Attalage, R., & Jayawardena, A. (2003). Roof orientation, roofing materials and roof surface colour: their influence on indoor thermal comfort in warm humid climates. *Energy for Sustainable Development, 7*(1), 16-27.
10. Lim, T. T., & Huang, X. (2007). Evaluation of kapok (Ceiba pentandra (L.) Gaertn.) as a natural hollow hydrophobic-oleophilic fibrous sorbent for oil spill

cleanup. *Chemosphere, 66*(5), 955-963. doi: 10.1016/j.chemosphere.2006.05.062

11. Makaremi, N., Salleh, E., Jaafar, M. Z., & GhaffarianHoseini, A. (2012). Thermal comfort conditions of shaded outdoor spaces in hot and humid climate of Malaysia. *Building and Environment, 48*, 7-14.
12. Mazor, M. H., Mutton, J. D., Russell, D. A., & Keoleian, G. A. (2011). Life cycle greenhouse gas emissions reduction from rigid thermal insulation use in buildings. *Journal of Industrial Ecology, 15*(2), 284-299.
13. McElroy, D., & Kimpflen, J. F. (1990). *Insulation materials, testing, and applications* (Vol. 1030): ASTM International.
14. Ong, K. S. (2011). Temperature reduction in attic and ceiling via insulation of several passive roof designs. *Energy Conversion and Management, 52*(6), 2405-2411. doi: 10.1016/j.enconman.2010.12.044
15. Papadopoulos, A. M., & Giama, E. (2007). Environmental performance evaluation of thermal insulation materials and its impact on the building. *Building and Environment, 42*(5), 2178-2187. doi: 10.1016/j.buildenv.2006.04.012
16. Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings, 40*(3), 394-398. doi: 10.1016/j.enbuild.2007.03.007
17. Rajalingam, K. (2013). A Case Study and Explorative Analysis of the Development of Nanotechnology in Malaysia. *Journal of Sustainable Development Studies, 5*(1).
18. Rajput, R. (2007). *A textbook of engineering thermodynamics*: Firewall Media.
19. Roof Insulation | Cool Roof Malaysia. Retrieved 27 October, 2014, from http://thermoshield.com.my/
20. Sisman, N., Kahya, E., Aras, N., & Aras, H. (2007). Determination of optimum insulation thicknesses of the external walls and roof (ceiling) for Turkey's different degree-day regions. *Energy Policy, 35*(10), 5151-5155. doi: 10.1016/j.enpol.2007.04.037
21. Song, W., & Yu, W. (2011). Study on radiative heat transfer property of fiber assemblies using FTIR. *Journal of Thermal Analysis and Calorimetry, 103*(3), 785-790.

22. Soubdhan, T., Feuillard, T., & Bade, F. (2005). Experimental evaluation of insulation material in roofing system under tropical climate. *Solar Energy, 79*(3), 311-320. doi: 10.1016/j.solener.2004.10.009
23. Tong, S., Li, H., Zingre, K. T., Wan, M. P., Chang, V. W. C., Wong, S. K., . . . Lee, I. Y. L. (2014). Thermal performance of concrete-based roofs in tropical climate. *Energy and Buildings, 76*, 392-401. doi: 10.1016/j.enbuild.2014.02.076
24. Tye, Y. Y., Lee, K. T., Wan Abdullah, W. N., & Leh, C. P. (2012). Potential of Ceiba pentandra (L.) Gaertn. (kapok fiber) as a resource for second generation bioethanol: effect of various simple pretreatment methods on sugar production. *Bioresour Technol, 116*, 536-539. doi: 10.1016/j.biortech.2012.04.025
25. Vijaykumar, K., Srinivasan, P., & Dhandapani, S. (2007). A performance of hollow clay tile (HCT) laid reinforced cement concrete (RCC) roof for tropical summer climates. *Energy and Buildings, 39*(8), 886-892.
26. Wang, Y., & Zhou, M. (2008). <Structure and Adsorptive Properties in Wastewater Treatment of Activated Carbon Fiber Based on Kapok.pdf>.
27. Wei, K., Lv, C., Chen, M., Zhou, X., Dai, Z., & Shen, D. (2014). Development and performance evaluation of a new thermal insulation material from rice straw using high frequency hot-pressing. *Energy and Buildings, 87*, 116-122. doi: 10.1016/j.enbuild.2014.11.026
28. Wijewardane, S., & Jayasinghe, M. T. R. (2008). Thermal comfort temperature range for factory workers in warm humid tropical climates. *Renewable Energy, 33*(9), 2057-2063. doi: 10.1016/j.renene.2007.11.009
29. Xiang, H.-f., Wang, D., & Liua, H.-c. (2013). Investigation on sound absorption properties of kapok fibers. *Chinese Journal of Polymer Science, 31*(3), 521-529.
30. Yew, M. C., Ramli Sulong, N. H., Chong, W. T., Poh, S. C., Ang, B. C., & Tan, K. H. (2013). Integration of thermal insulation coating and moving-air-cavity in a cool roof system for attic temperature reduction. *Energy Conversion and Management, 75*, 241-248. doi: 10.1016/j.enconman.2013.06.024
31. Yu, J., Tian, L., Yang, C., Xu, X., & Wang, J. (2011). Optimum insulation thickness of residential roof with respect to solar-air degree-hours in hot

summer and cold winter zone of china. *Energy and Buildings, 43*(9), 2304-2313. doi: 10.1016/j.enbuild.2011.05.012

32. Zulkifli, I. S. M., Yajid, M. A. M., Hamdan, H., & Muhid, M. N. M. (2014). Maerogel: Alternative for Thermal Barrier Coating Topcoat. *Advanced Materials Research, 845*, 330-334.

33. ASTM D638 (2002). Standard Test Method for Tensile Properties of Plastics.

34. Raden Shield. Product Datasheet. Monier Sdn Bhd.

35. Thermal Rock B (Blancket). General Product Information. RoCKWOOL Malaysia Sdn Bhd.

36. Low Density Polyethylene (LDPE). Product Data. Lotte Chemical Titan.

APPENDICES

<u>Physical Properties of Composites</u>

Sample	Label	Mass (g)	Thickness (mm) 1	2	3	4	5	Average	Volume m^3	Density (kg/m^3)	
Aluminum Foil + LDPE + Maerogel	A1	8.571	3.845	3.847	3.824	3.835	3.829	**3.836**	9624.52	890.54	**895.22**
	A2	8.585	3.831	3.845	3.847	3.852	3.838	**3.843**	9641.08	890.46	
	A3	8.61	3.811	3.793	3.786	3.789	3.811	**3.798**	9529.18	903.54	
	A4	8.542	3.801	3.802	3.789	3.792	3.78	**3.793**	9516.14	897.63	
	A5	8.576	3.811	3.806	3.824	3.858	3.819	**3.824**	9593.41	893.95	
Stone Wool + LDPE + Maerogel	S1	8.965	3.826	3.848	3.842	3.837	3.835	**3.838**	9628.54	931.09	**933.26**
	S2	8.977	3.815	3.831	3.834	3.827	3.831	**3.828**	9603.45	934.77	
	S3	9.122	3.905	3.892	3.893	3.91	3.898	**3.900**	9784.10	932.33	
	S4	9.044	3.856	3.894	3.874	3.856	3.821	**3.860**	9685.24	933.79	
	S5	8.989	3.829	3.815	3.866	3.826	3.837	**3.835**	9621.01	934.31	
Kapok Fibre + LDPE + Maerogel	K1	8.617	3.81	3.825	3.837	3.797	3.798	**3.813**	9567.82	900.62	**905.50**
	K2	8.628	3.786	3.783	3.767	3.739	3.788	**3.773**	9465.45	911.53	
	K3	8.713	3.835	3.81	3.78	3.796	3.838	**3.812**	9563.81	911.04	
	K4	8.704	3.863	3.848	3.832	3.862	3.849	**3.851**	9661.66	900.88	
	K5	8.629	3.794	3.812	3.835	3.798	3.795	**3.807**	9551.26	903.44	

<u>Thermal Properties of Composites</u>

Sample	Label	Thermal Analyzer Code	Thermal Conductivity, k (W/mK)							Specific Heat Capacity (J/kg/K)						
			1	2	3	4	5	Averag		1	2	3	4	5	Averag	
Aluminum Foil + LDPE + Maerogel	A1	126	0.848	0.855	0.858	0.858	0.864	**0.857**	**0.824**	754.05	755.31	755.7	755.78	756.64	**755.496**	**749.659**
	A2	127	0.720	0.727	0.730	0.732	0.736	**0.729**		731.44	732.76	733.35	733.81	734.57	**733.186**	
	A3	122	0.851	0.864	0.866	0.868	0.869	**0.864**		754.68	756.68	756.94	757.34	757.54	**756.636**	
	A4	123	0.753	0.758	0.759	0.759	0.759	**0.758**		737.8	738.69	738.76	738.82	738.9	**738.594**	
	A5	128	0.906	0.914	0.914	0.918	0.920	**0.914**		763.2	764.26	764.32	764.95	765.19	**764.384**	
Stone Wool + LDPE + Maerogel	S1	114	0.704	0.721	0.722	0.723	0.727	**0.719**	**0.668**	728.37	731.75	731.93	732.04	732.94	**731.406**	**720.453**
	S2	131	0.618	0.632	0.633	0.634	0.636	**0.631**		710.3	713.36	713.73	713.89	714.38	**713.132**	
	S3	116	0.691	0.626	0.607	0.596	0.592	**0.622**		725.86	712.06	707.98	705.34	704.47	**711.142**	
	S4	118	0.769	0.771	0.762	0.769	0.762	**0.767**		740.72	741.03	739.37	740.65	739.35	**740.224**	
	S5	119	0.615	0.597	0.599	0.595	0.596	**0.600**		709.77	705.58	706.02	705.11	705.33	**706.362**	
Kapok Fibre + LDPE + Maerogel	K1	102	0.505	0.504	0.500	0.500	0.502	**0.502**	**0.485**	683.3	683.03	681.94	681.94	682.54	**682.550**	**677.529**
	K2	104	0.477	0.454	0.444	0.444	0.439	**0.452**		675.88	669.51	666.68	666.67	665.32	**668.812**	
	K3	105	0.570	0.562	0.562	0.556	0.559	**0.562**		699.26	697.4	697.53	696.06	696.62	**697.374**	
	K4	106	0.454	0.437	0.427	0.429	0.426	**0.435**		669.48	664.83	661.77	662.38	661.7	**664.032**	
	K5	108	0.476	0.474	0.471	0.475	0.471	**0.473**		675.65	674.9	674.29	675.31	674.24	**674.878**	

Date	Time (Hours)	Aluminum Foil + LDPE + Maerogel			Stone Wool + LDPE + Maerogel			Kapok Fibre + LDPE + Maerogel		
		T_{in} °C	T_{out} °C	T_{out}-T_{in} °C	T_{in} °C	T_{out} °C	T_{out}-T_{in} °C	T_{in} °C	T_{out} °C	T_{out}-T_{in} °C
1st JAN (DAY 1)	9:00 AM	27.6	27.4	-0.2	27.6	27.4	-0.2	27.7	27.4	-0.3
	10:00 AM	28.1	29.3	1.2	28.1	29.3	1.2	28.2	29.3	1.1
	11:00 AM	28.9	30.1	1.2	28.9	30.1	1.2	28.9	30.1	1.2
	12:00 PM	29.7	30.8	1.1	29.7	30.8	1.1	29.5	30.8	1.3
	1:00 PM	30.4	31.6	1.2	30.3	31.6	1.3	30.1	31.6	1.5
	2:00 PM	30.8	29.1	-1.7	30.8	29.1	-1.7	30.5	29.1	-1.4
	3:00 PM	31.0	26.5	-4.5	30.9	26.5	-4.4	30.6	26.5	-4.1
	4:00 PM	30.1	24.0	-6.1	30.1	24.0	-6.1	29.8	24.0	-5.8
	5:00 PM	29.1	24.6	-4.5	29.1	24.6	-4.5	29.0	24.6	-4.4
2nd JAN (DAY 2)	9:00 AM	27.6	27.4	-0.2	27.7	27.4	-0.3	27.8	27.4	-0.4
	10:00 AM	28.2	29.5	1.3	28.2	29.5	1.3	28.3	29.5	1.2
	11:00 AM	29.2	30.5	1.3	29.2	30.5	1.3	29.1	30.5	1.4
	12:00 PM	30.4	31.5	1.1	30.4	31.5	1.1	30.2	31.5	1.3
	1:00 PM	31.0	32.5	1.5	31.0	32.5	1.5	30.7	32.5	1.8
	2:00 PM	31.2	30.1	-1.1	31.1	30.1	-1.0	30.8	30.1	-0.7
	3:00 PM	30.9	27.6	-3.3	30.9	27.6	-3.3	30.6	27.6	-3.0
	4:00 PM	30.2	25.2	-5.0	30.2	25.2	-5.0	30.0	25.2	-4.8
	5:00 PM	29.4	25.5	-3.9	29.4	25.5	-3.9	29.2	25.5	-3.7
3rd JAN (DAY 3)	9:00 AM	28.0	27.4	-0.6	28.0	27.4	-0.6	28.2	27.4	-0.8
	10:00 AM	28.5	29.3	0.8	28.5	29.3	0.8	28.7	29.3	0.6
	11:00 AM	29.3	30.3	1.0	29.3	30.3	1.0	29.3	30.3	1.0
	12:00 PM	30.2	31.3	1.1	30.2	31.3	1.1	30.1	31.3	1.2

	1:00 PM	30.8	32.3	1.5	30.8	32.3	1.5	30.7	32.3	1.6
	2:00 PM	31.3	32.2	0.9	31.3	32.2	0.9	31.0	32.2	1.2
	3:00 PM	31.5	32.1	0.6	31.5	32.1	0.6	31.2	32.1	0.9
	4:00 PM	31.3	32.0	0.7	31.3	32.0	0.7	31.1	32.0	0.9
	5:00 PM	31.0	31.0	0.0	31.0	31.0	0.0	30.8	31.0	0.2
4th JAN (DAY 4)	9:00 AM	28.6	27.4	-1.2	28.6	27.4	-1.2	28.7	27.4	-1.3
	10:00 AM	29.0	29.1	0.1	29.0	29.1	0.1	29.2	29.1	-0.1
	11:00 AM	29.7	30.1	0.4	29.8	30.1	0.3	29.8	30.1	0.3
	12:00 PM	30.5	31.2	0.7	30.5	31.2	0.7	30.5	31.2	0.7
	1:00 PM	31.3	32.2	0.9	31.3	32.2	0.9	31.1	32.2	1.1
	2:00 PM	31.9	32.2	0.3	31.9	32.2	0.3	31.6	32.2	0.6
	3:00 PM	32.3	32.2	-0.1	32.3	32.2	-0.1	32.0	32.2	0.2
	4:00 PM	32.1	32.2	0.1	32.0	32.2	0.2	31.8	32.2	0.4
	5:00 PM	31.5	30.8	-0.7	31.5	30.8	-0.7	31.3	30.8	-0.5
5th JAN (DAY 5)	9:00 AM	29.0	27.7	-1.3	29.0	27.7	-1.3	29.2	27.7	-1.5
	10:00 AM	29.5	29.6	0.1	29.5	29.6	0.1	29.6	29.6	0.0
	11:00 AM	30.3	30.6	0.3	30.3	30.6	0.3	30.3	30.6	0.3
	12:00 PM	31.4	31.5	0.1	31.4	31.5	0.1	31.3	31.5	0.2
	1:00 PM	32.1	32.5	0.4	32.0	32.5	0.5	31.8	32.5	0.7
	2:00 PM	32.5	32.0	-0.5	32.5	32.0	-0.5	32.2	32.0	-0.2
	3:00 PM	32.7	31.5	-1.2	32.7	31.5	-1.2	32.4	31.5	-0.9
	4:00 PM	32.4	31.0	-1.4	32.3	31.0	-1.3	32.1	31.0	-1.1
	5:00 PM	31.7	29.7	-2.0	31.7	29.7	-2.0	31.5	29.7	-1.8